SuperTAPP n+
Voltage Control Relay

User Manual

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1 Introduction

The SuperTAPP n+ voltage control relay is used to regulate voltage on power transformers equipped with an on load tap changer (OLTC). Voltage regulation on electrical networks must take account of the increasing amount of embedded generation which is being connected. The SuperTAPP n+ relay is designed to offer functionality to address this along with ‘standard’ requirements.

This user manual describes the design, functionality, operation and implementation of the SuperTAPP n+ voltage control relay.

It is important to note that the SuperTAPP n+ relay is normally accompanied by the RTMU monitor and control relay (Fundamentals product) to form a complete AVC (automatic voltage control) system. Details of the RTMU relay can be found in a separate user manual.

2 Key Features

The main functions offered by SuperTAPP n+ are as follows:

- Comprehensive voltage regulation for power transformers with on-load tap-changers
- Functions for embedded generation and reverse power
- Easily configurable for full range of application complexity
- Future proof
- Multiple CT and VT inputs with flexible rating range
  - Customisable analogue inputs
  - Voltage averaging and load summation for double winding transformers
  - Feeder current measurements
- Load drop compensation (LDC)
  - Load exclusion and correction for troublesome loads
- Parallel operation of up to 6 transformers
  - Enhanced TAPP principle (Transformer Automatic Paralleling Package)
- OLTC Monitoring:
  - Tap position indication*
  - Tap changer runaway prevention*
  - Tap changer blocking*
  - Fuse-failure detection*
- SCADA Communications (DNP3, IEC61850)†
- Web monitoring†
- User friendly HMI with push button and digital display
- Integral instrumentation to display measurements and calculations
- Digital inputs and outputs
- Voltage adjustments for load shedding/boosting
- Continuous self-supervision of hardware and software for enhanced system reliability
  - Auto-diagnostic fault indication to facilitate troubleshooting

* available only when used in conjunction with an RTMU relay
† available only when used in conjunction with an ENVOY unit

The SuperTAPP n+ voltage control relay is available as a ‘basic’ model or as an ‘advanced’ model. Table 1 shows the differences between the two models.

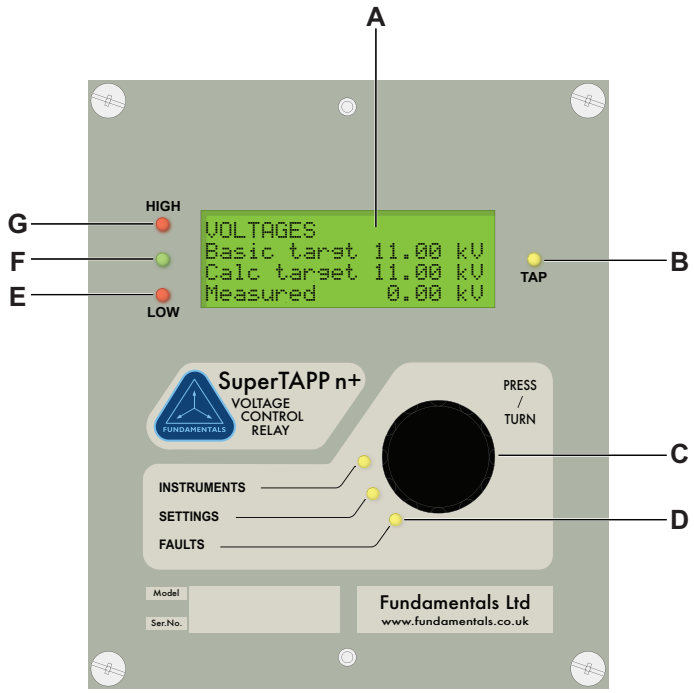
Table 1 – Differences between basic and advanced models

Feature	Basic	Advanced
# activated VT inputs	1	2
# activated CT inputs	1	3
Load Drop Compensation	✓	✓
Transformer Paralleling	✓	✓
Voltage Reduction	✓	✓
Embedded Generation Functions	✗	✓
Load Exclusion	✗	✓
Load Inclusion	✗	✓
Load Correction	✗	✓
Averaging for double-secondary windings	✗	✓
VT Switching	✗	✓

The basic model is easily upgraded to an advanced model without hardware or software modifications to the relay. In order to perform an upgrade, the user simply programs a ‘key code’ (purchased from Fundamentals Ltd) into the relay settings.

3 Quick SuperTAPP n+ Guide

This section provides a brief description of the relay indications and available information to help users quickly identify the operational state of the relay. More detailed descriptions are presented in later sections.



A. Four line LCD for display of measurement and status information

B. Tap in progress indication LED

C. Control knob for menu system navigation and settings changes

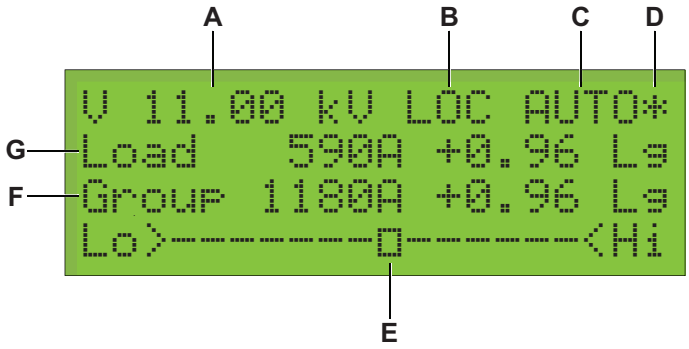
D. LED indications for menu system navigation

E. Voltage low (solid) / Voltage very low (flashing)

F. Normal voltage (solid) / Overload (flashing)

G. Voltage high (solid) / Voltage very high (Flashing)

Figure 1 – SuperTAPP n+ relay fascia



A. Measured voltage indication

B. Control level indication: Local / Remote

C. Operation mode indication: Auto/ Non-auto

D. Alternative settings indication:✳ = on

E. Bar chart indication of voltage level OR
Time to tap indication OR Error message

F. Group load measurement OR Error message

Figure 2 – LCD display

4 Relay Operation

4.1 Introduction

The SuperTAPP n+ relay has 2 VT inputs and 3 CT inputs available for use. The basic model has one VT and one CT activated. The advanced model has all inputs activated for use. The description of operation presented in the following sections is valid for basic and advanced models.

4.2 Basic Principle

Basic relay operation can be described with reference to Figure 3 which shows a single tap changing transformer supplying a busbar with two outgoing feeders. Normally, the tap changer is on the high voltage side of the transformer and the VT and CT are on the low voltage side.

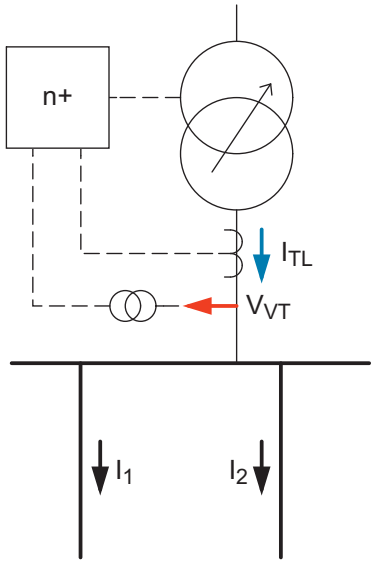


Figure 3 – Simplified AVC application

The voltage control relay measures the voltage (V_{VT}) and the current (I_{TL}). The measured voltage is used for regulation, but also as a reference to calculate the real and reactive components of the current.

4.3 Real and Reactive Components

The real and reactive components of measured current are useful for display purposes but are also very important for various relay calculations (as described throughout this manual). The relay uses the measured voltage as a reference to calculate the relative phase of the measured current.

For correct calculation of real and reactive components, the phases of VT and CT inputs must be configured correctly in the settings (see section 11.3.2). The relay uses the phase configurations to make the appropriate adjustments to measured angles between the voltage and current. Figure 4 shows how the relay works in this respect.

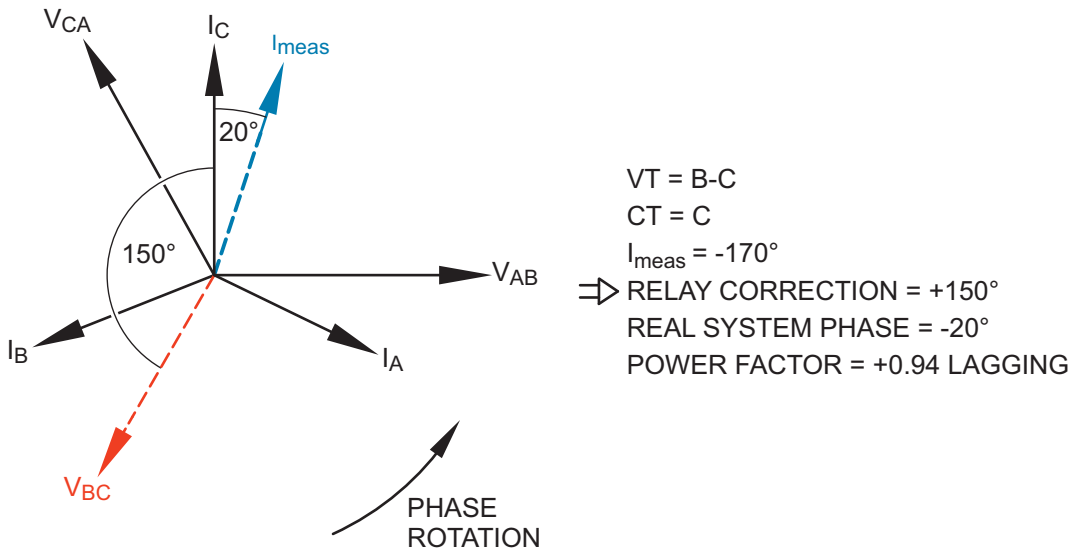


Figure 4 – Relay adjustment for power factor calculation

Correct selection of the voltage/current phase relationship is critical for operation of the relay. Comprehensive instrumentation is available to aid this including:

- Secondary values of all current measurements with magnitude and angle with respect to the voltage reference
- Primary values of all current measurements with magnitude and power factor

4.4 Levels of Control

There are two levels of control for voltage control as follows:

- Local – tap changer is controlled at the substation (at the tap changer or at the tap changer control panel/relay)
- Remote – tap changer is controlled via the relay by SCADA communications (DNP3, IEC 61850 etc.)*

* SCADA communications is available only with an accompanying ENVOY unit (communications platform developed specifically for use with the SuperTAPP n+ relay – see separate datasheet)

The relay has inputs available to use to switch between Local and Remote control modes (see section 10.2.7 for more detail). These are only used where SCADA communications is used (DNP3, IEC 61850 etc.), otherwise the relay is permanently in Local control mode.

4.5 Modes of Operation

There are two modes of operation for the relay as follows:

- Auto Mode – relay controls the tap changer
- Non-Auto Mode – operator controls the tap changer

These modes of operation can exist in Local and Remote control to give the following combinations of control mode:

- Local Auto – tap changer controlled by the relay
- Local Non-Auto – tap changer manually controlled by an operator at the substation (at the tap changer or at the control panel/relay)
- Remote Auto – tap changer controlled by the relay but influenced by SCADA communications (DNP3, IEC 61850 etc.)
- Remote Non-Auto – tap changer controlled via an operator by remote raise and lower commands over SCADA communications (DNP3, IEC 61850 etc.)

The relay has inputs available to use to switch between Auto and Non-Auto control modes (see section 10.2.7 for more detail). Auto and Non-Auto modes of operation are considered in the following sections.

4.5.1 Auto Mode

For relay operation in automatic mode, the measured voltage (V_{VT}) is compared with the target voltage of the relay (V_{tgt}). If the difference exceeds the bandwidth setting, a tap changer operation is initiated to adjust the transformer voltage to a satisfactory level. To avoid tap changer operations for short term voltage fluctuations, it is normal practice for a time delay to take place prior to initiation of the tap change. This is shown in Figure 5 where the measured voltage (V_{VT}) increases until it is outside of the dead-band, at which point the VCR initiates a 'lower' command* after a time delay and the measured voltage returns to normal.

*lower in terms of voltage, not necessarily tap position number (some tap changers increase the voltage when they move to a lower tap position – see section 10.2.4 for more information about raise and lower outputs).

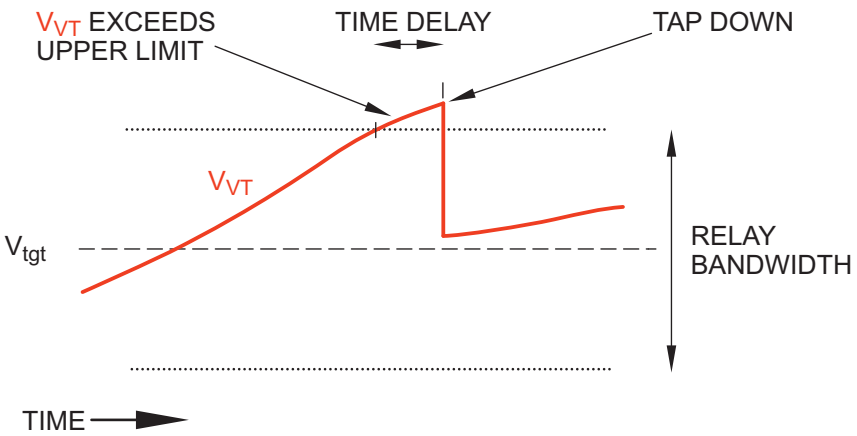


Figure 5 – Tap changer operation time delay

The target voltage of the relay (V_{tgt}) comprises several components which are calculated in real time according to the prevailing network conditions as measured by the relay. This is discussed in more detail in the following section.

Target Voltage

The relay target voltage is a dynamic quantity and is affected by several factors associated with the voltage control system. The calculation of the relay target voltage is shown in Equation 1:

$$V_{tgt} = V_{basic} + V_{adj} + V_{circ} + V_{LDC} + V_{gen} \quad (1)$$

where

V_{tgt}	=	relay target voltage used for control
V_{basic}	=	relay basic target voltage setting
V_{adj}	=	voltage target adjustments applied via status inputs
V_{circ}	=	circulating current bias voltage
V_{LDC}	=	load drop compensation bias voltage
V_{gen}	=	embedded generator bias voltage*

* available only with an advanced model

These quantities are all expressed in % values where 100% voltage is the nominal voltage of the network which the transformer is supplying. Each quantity is considered in the Applications section 8.

Bandwidth

The bandwidth setting of the relay defines the sensitivity to voltage fluctuations. Reducing the bandwidth setting will maintain the voltage closer to the target level (i.e. increase the voltage control accuracy), but will increase the number of tap changer operations. It is normally represented by a ±% value based on the system nominal voltage.

The bandwidth setting is determined by the voltage step of the tap changer. To optimise the number of tap changer operations it should be set to one tap step (as shown in Figure 5). Care should be taken not to set the bandwidth lower than half a tap step since this will result in 'hunting', where one tap operation can cause the voltage to move across the bandwidth and result in a call for another tap operation in the opposite direction (see Figure 6).

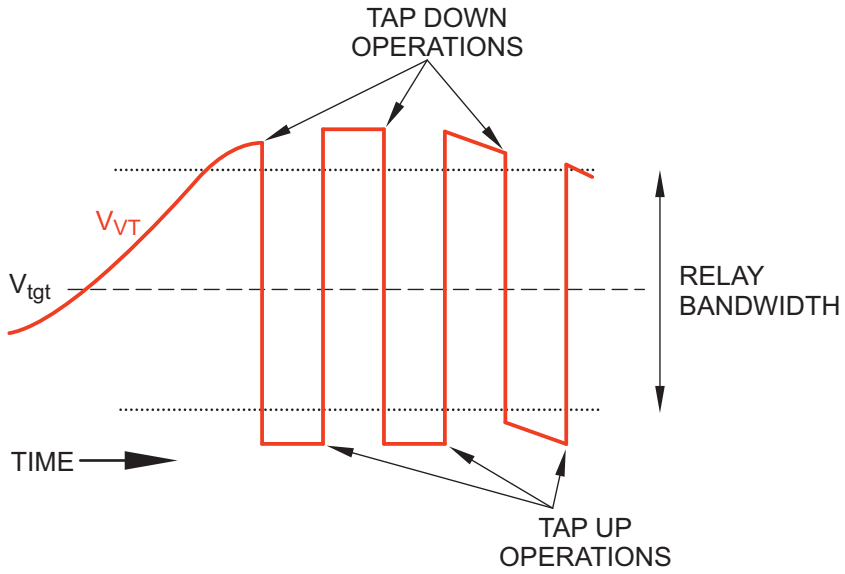


Figure 6 – Tap changer 'hunting'

Time Delays

When the need for a voltage adjustment is sensed, an initial time delay takes place before the relay issues the raise/lower command. This initial time delay is included to ensure that unnecessary operations do not occur for transient voltage deviations.

The delay is presented on the relay screen as 'time to tap', which counts down from the setting to zero, at which point a tap changer operation is initiated. If during the timing cycle the voltage returns

to normal, the time delay count will increase at the same rate back to the initial time delay setting (but not displayed on the screen).Where further corrections are required following an initial time delay and tap changer operation, an inter-tap time delay is used. If during the inter-tap timing cycle the voltage returns to normal, the inter-tap time count will be reset and the initial time delay count will increment from zero towards the initial time setting. The effect of these timers is shown in Figure 7.

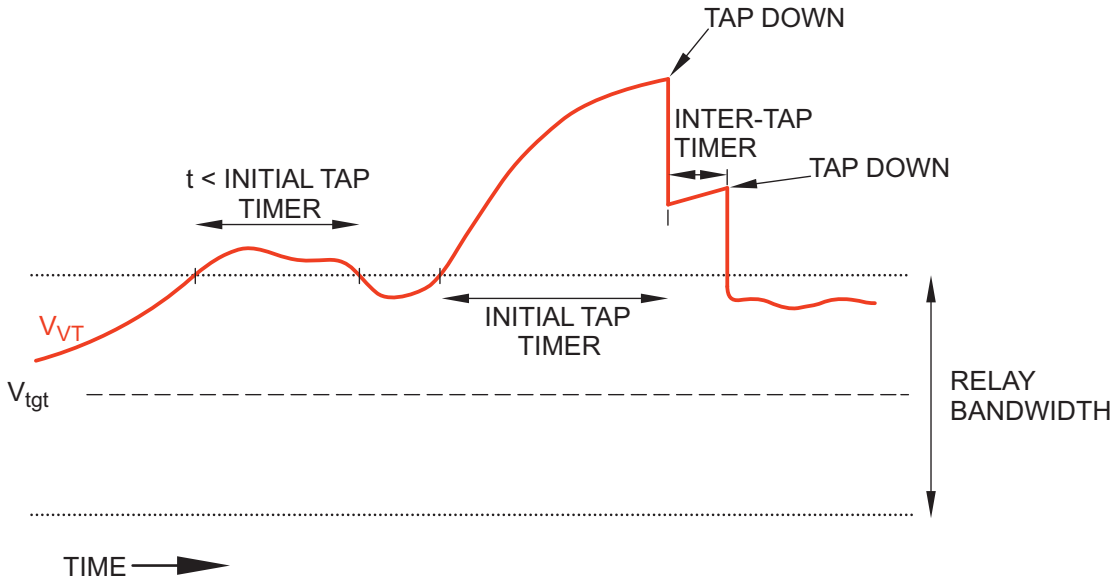


Figure 7 – Multiple tap changer operations

The inter-tap time should be set to longer than the operation time of the tap changer (for safety at least 25% longer than the tap changer operation time). This is to avoid attempted raise/lower operations while the tap changer is in operation (which can cause a lockout if an RTMU relay is being used).

The initial time delay for the first period is adjustable from 10 seconds to 120 seconds. The inter-tap delay operative for all successive time delays is adjustable from 5 seconds to 120 seconds.

If the voltage cannot be corrected (e.g. tap changer mechanism fault or end of range), the relay will stop issuing raise/lower signals when the associated AVC alarm has been raised (dependent on the relay alarm time setting).

Fast Tap

Under some circumstances the initial time delay can be over-ridden and a corrective tap changer operation can be initiated after a short, fixed time delay of 4 seconds. The conditions under which fast tapping can take place are as follows:

- High voltage 2% above band*
- Low voltage 2% below band*
- Detection of a measuring voltage > 80% of nominal after a previous zero voltage (<25%)
- Switching to ‘Auto’ when the relay has been in ‘Non-Auto’ for a period of more than the ‘initial time delay’
- At power on **
- Following a change to the relay basic voltage target (-3%, -6% etc.).
- When preparing for switch-out

* this must be configured in the relay settings where the user can specify under which voltage conditions a fast tap takes place

** subject to internal checks relating to measurement and communications data

4.5.2 Non-Auto Mode

In this mode the relay maintains measurements and indications according to the operational state (see section 5) but does not issue tap changer operations or operational alarms. Normally this would represent situations where the tap changer is operated by an operator, which could be at one of the following locations:

- Relay control panel (panel push buttons or accompanying RTMU relay switches*)
- At the tap changer
- Remote control (SCADA communications)

*see separate user manual for information relating to the RTMU relay

4.6 Peer-to-Peer Communications

4.6.1 Introduction

It is common to operate multiple power transformers in parallel for security of supply. SuperTAPP n+ can accommodate parallel operation of up to six units using the peer-to-peer communications bus system (CAN bus). Units operating together on the CAN bus should have the same software version to ensure compatibility.

In order to aid understanding of relay operation, some terminology is introduced by reference to Figure 8 which shows multiple SuperTAPP n+ relays as a typical voltage control scheme with peer-to-peer communications. Implementation details of the CAN bus is described in section 10.2.8.

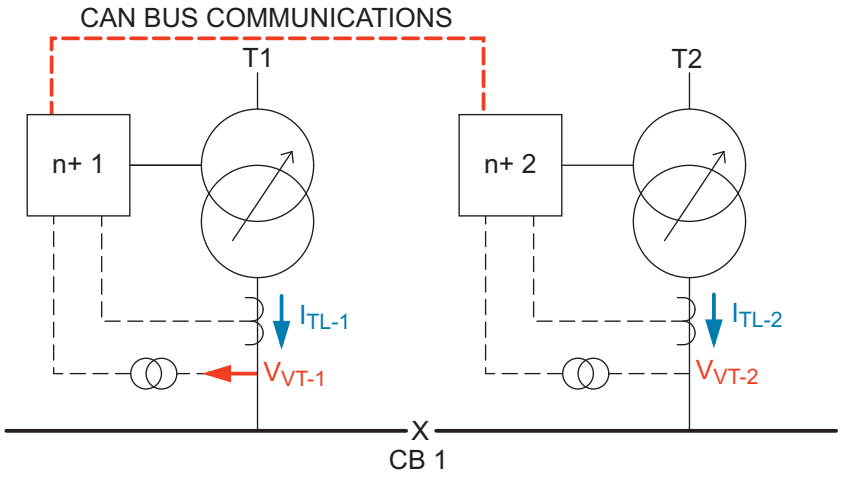


Figure 8 – Peer-to-peer communications on CAN bus

4.6.2 Group Load

Each relay on the CAN bus reports measurement and status information which is received by all relays on the bus. Each relay has a transformer ID and a group ID which are configured in the settings. Relays in the same group will use measurement data to calculate the group load as follows:

$I_{group} = I_{TL-1} + I_{TL-2} + ...I_{TL-n}$

where transformers 1 to n are in the same group*

The group load is important for operational calculations (see the Applications section 8.) and is displayed with the individual transformer measured current on the default screen of the relay.

Each unit on the CAN bus should have a unique transformer ID, otherwise there will be communication errors which could result in load summation inaccuracy.

*there are some situations (e.g. embedded generation) where this equation calculation does not hold – see Advanced Applications section 9.

4.6.3 Topology Changes

In order that CAN bus information is used correctly, the grouping must accurately represent which relays are operating in parallel. Table 2 shows an example of how the grouping should change according to the status of the bus-section circuit breaker shown in Figure 8.

Table 2 – Group load according to bus section status

CB Status		Closed	Open
T1	**Transformer ID**	1	1
	Group ID	1	1
	Group Load	$I_{TL2} + I_{TL2}$	I_{TL1}
T2	**Transformer ID**	2	2
	Group ID	1	2
	Group Load	$I_{TL2} + I_{TL2}$	I_{TL2}

It is possible to change the group ID (and other settings as appropriate) by use of a subset of the settings which can be adopted when the dedicated ‘alternative settings’ status input is activated. Normal settings will be used when the input is de-activated/de-energised.

This can be implemented automatically by use of an auxiliary contact on the circuit breaker, or manually from the control room. The ‘alternative settings’ is described in more detail in section 10.2.7 (digital status inputs).

5 Operational States

Figure 9 shows the various operational states that will be generated with the associated voltage and loading conditions. Each state is described in a corresponding section with example screen shots to show relay indications.

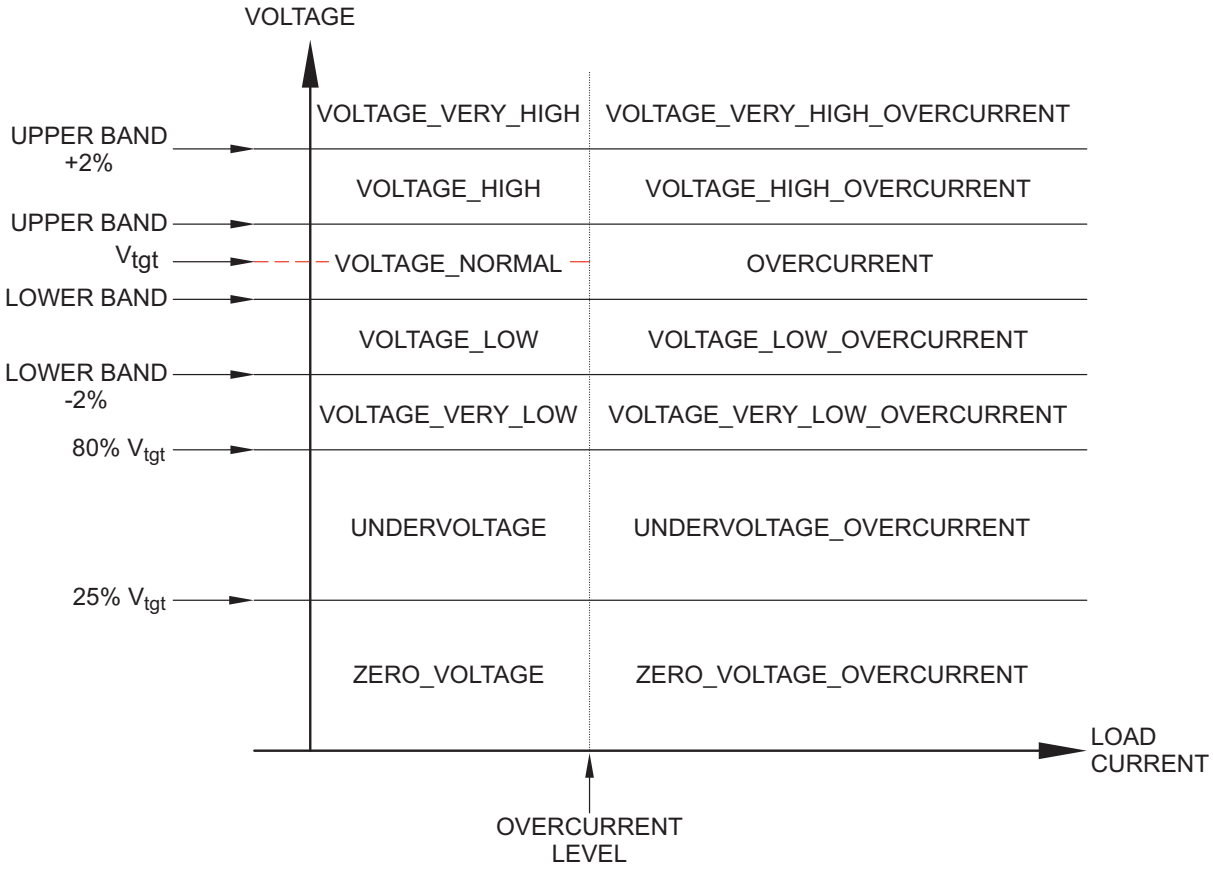


Figure 9 – Operational states

VOLTAGE_NORMAL

- Voltage is within the deadband.
- Load current is below the relay overcurrent setting.
- Raise/lower operations permitted.

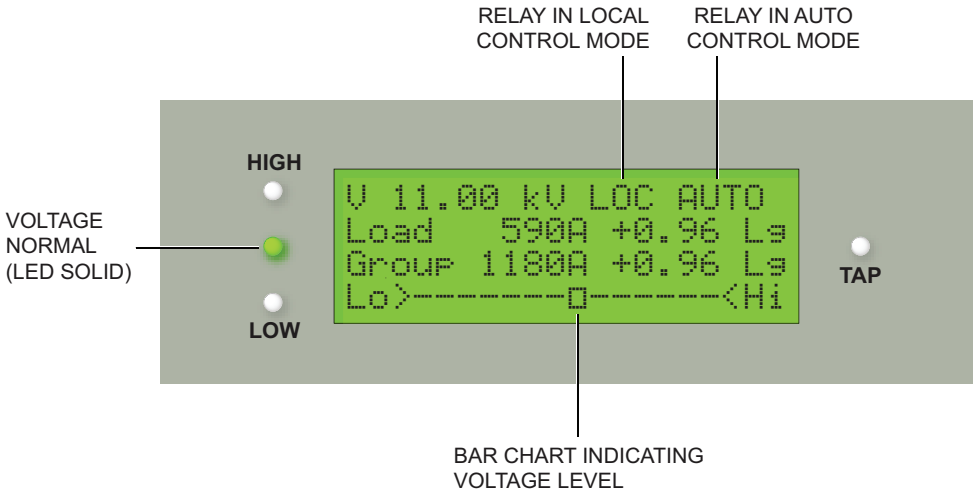


Figure 10 – VOLTAGE_NORMAL

VOLTAGE_HIGH

- Voltage is up to 2% higher than the upper band level.
- Load current is below the relay overcurrent setting.
- In automatic mode the relay will count down to a corrective tap changer operation.
- In non-auto mode the relay will display an out-of-band condition but will not issue tap changer operation commands.

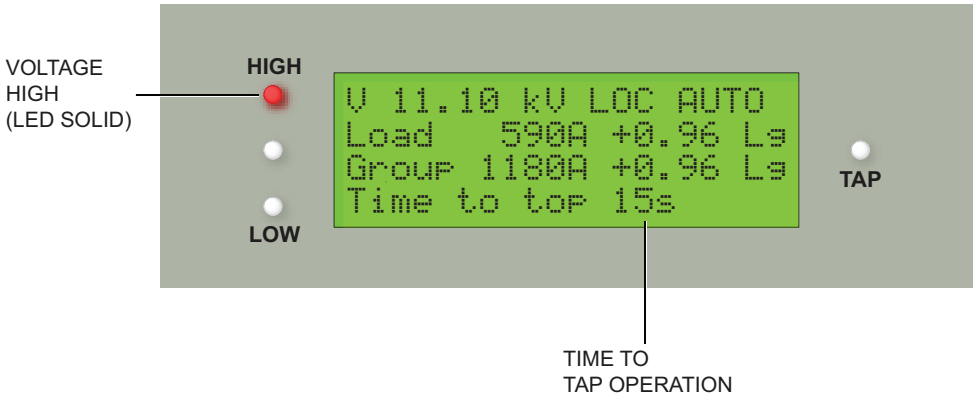


Figure 11 – VOLTAGE_HIGH (automatic mode)

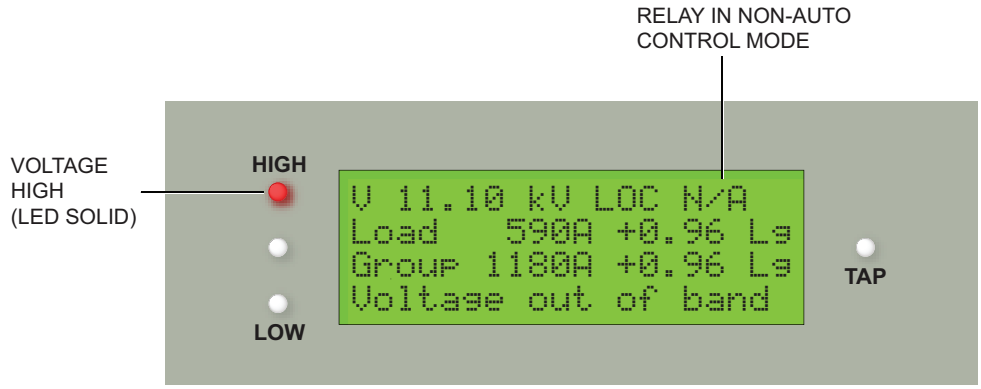


Figure 12 – VOLTAGE_HIGH (non-automatic mode)

VOLTAGE_LOW

- Voltage is up to 2% lower than the lower band level.
- Load current is below the relay overcurrent setting.
- In automatic mode the relay will count down to a corrective tap changer operation.
- In non-auto mode the relay will display an out-of-band condition but will not issue tap changer operation commands.

Figure 13 – VOLTAGE_LOW

VOLTAGE_VERY_HIGH

- Voltage exceeds the upper band + 2%.
- Load current is below the relay overcurrent setting.
- Fast tap operations can be configured for this state where the initial timer is bypassed for a time delay of 4 seconds.
- In automatic mode the relay will count down to a corrective tap changer operation.
- In non-auto mode the relay will display an out-of-band condition but will not issue tap changer operation commands.

Figure 14 – VOLTAGE_VERY_HIGH

VOLTAGE_VERY_LOW

- Voltage level is between the lower band - 2% and 80% of target.
- Load current is below the relay overcurrent setting.
- Fast tap operations can be configured for this state where the initial timer is bypassed for a time delay of 4 seconds.
- In automatic mode the relay will count down to a corrective tap changer operation.
- In non-auto mode the relay will display an out-of-band condition but will not issue tap changer operation commands.

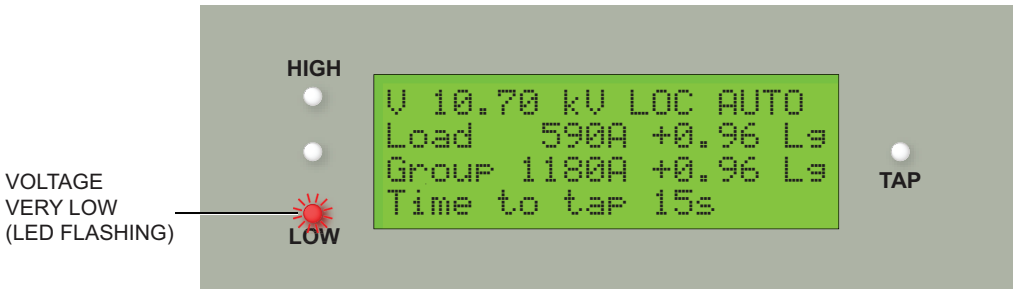


Figure 15 – VOLTAGE_VERY_LOW

UNDERVOLTAGE

- Voltage level is between 80% and 25% of the relay target level.
- Load current is below the relay overcurrent setting.
- No tap changer operations permitted.

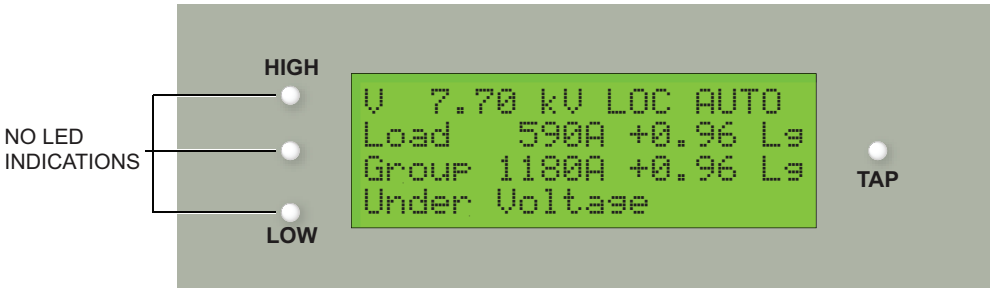


Figure 16 – UNDERVOLTAGE

ZERO_VOLTAGE

- Voltage level is below 25% of the relay target level.
- Load current is below the relay overcurrent setting.
- No tap changer operations permitted.

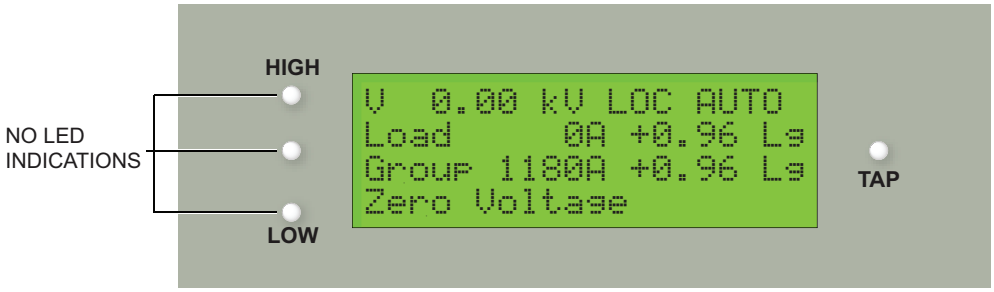


Figure 17 – ZERO_VOLTAGE

OVERCURRENT

- Voltage is within the deadband.
- Load current is above the relay overcurrent setting.
- No tap changer operations permitted.

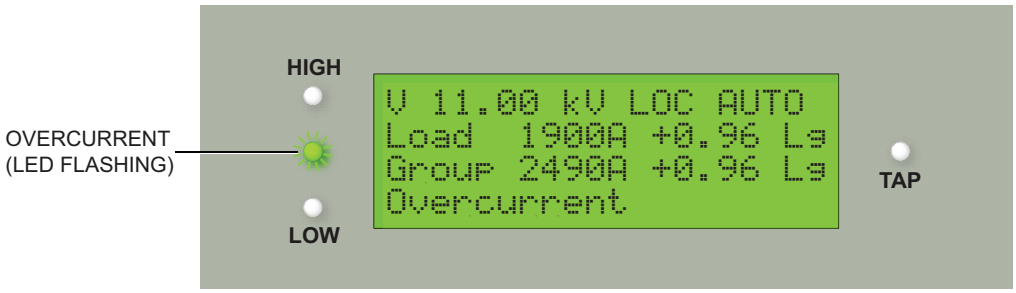


Figure 18 – OVERCURRENT

VOLTAGE_HIGH_OVERCURRENT

- Voltage is up to 2% higher than the upper band level.
- Load current is above the relay overcurrent setting.
- No tap changer operations permitted.

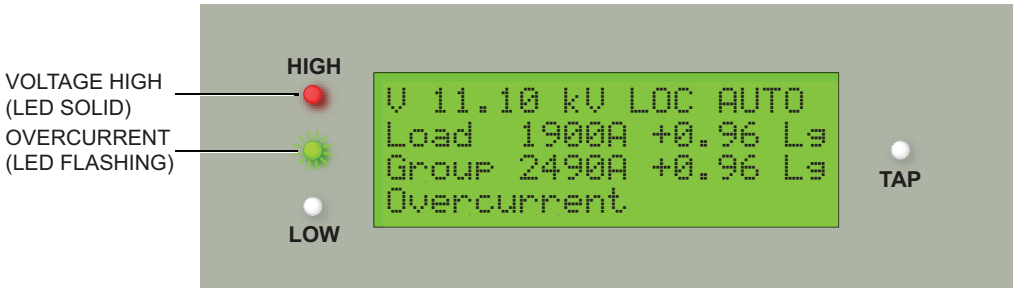


Figure 19 – VOLTAGE_HIGH_OVERCURRENT

VOLTAGE_LOW_OVERCURRENT

- Voltage is up to 2% lower than the lower band level.
- Load current is above the relay overcurrent setting.
- No tap changer operations permitted.

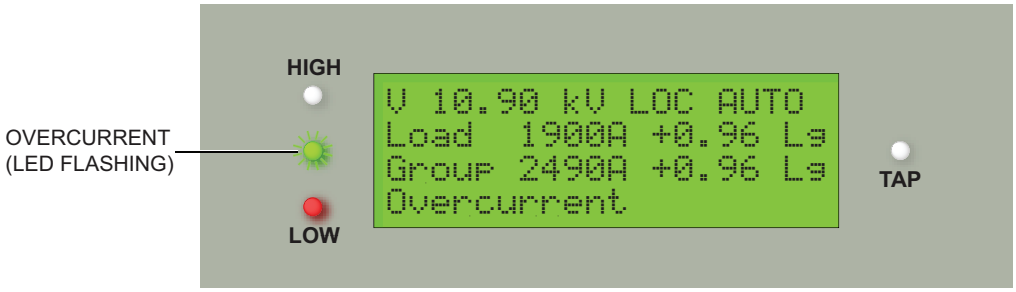


Figure 20 – VOLTAGE_LOW_OVERCURRENT

VOLTAGE_VERY_HIGH_OVERCURRENT

- Voltage exceeds the upper band + 2%.
- Load current is above the relay overcurrent setting.
- No tap operations are permitted.

Figure 21 – VOLTAGE_VERY_HIGH_OVERCURRENT

VOLTAGE_VERY_LOW_OVERCURRENT

- Voltage level is between the lower band - 2% and 80% of target.
- Load current is above the relay overcurrent setting.
- No tap operations are permitted.

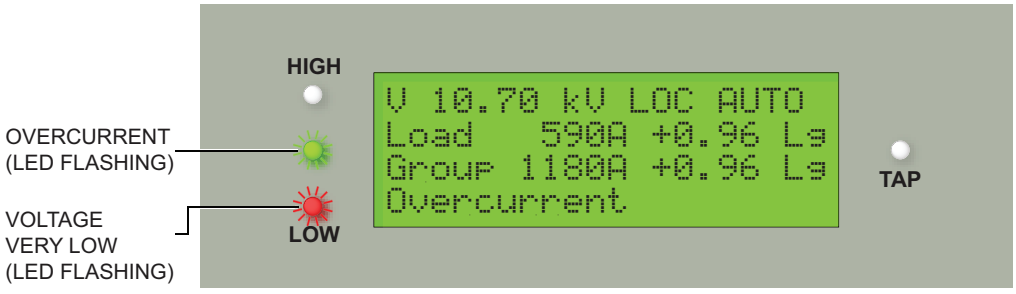


Figure 22 – VOLTAGE_VERY_LOW_OVERCURRENT

UNDERVOLTAGE_OVERCURRENT

- Voltage level is between 80% and 25% of the relay target level.
- Load current is above the relay overcurrent setting.
- No tap changer operations permitted.

Figure 23 – UNDERVOLTAGE_OVERCURRENT

ZERO_VOLTAGE_OVERCURRENT

- Voltage level is below 25% of the relay target level.
- Load current is above the relay overcurrent setting.
- No tap changer operations permitted.

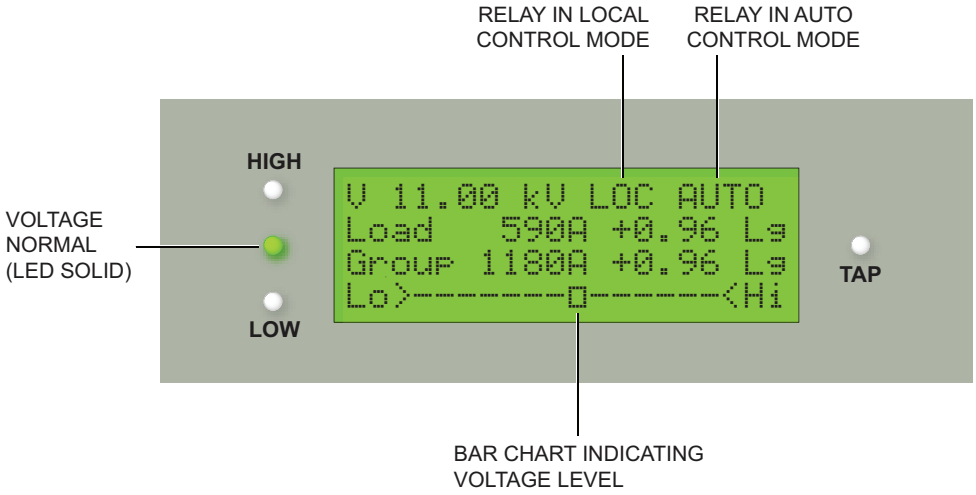


Figure 24 – ZERO_VOLTAGE_OVERCURRENT

6 Failure States

The relay is self-monitoring and can detect various failure states which may render it non-functional and requiring attention. Corresponding alarm outputs are available and are considered in a later section.

6.1 Hardware Errors

There are a number of problems which the relay can detect and report relating to internal hardware:

- Hardware error - faulty relay hardware
- Measurement error - frequency problems (> 3Hz deviation)
- Uncalibrated input - analogue input calibration error

The response of the relay under these conditions is dependent on whether the faulty hardware is critical for voltage control functions. Critical hardware includes the following:

- Main processor
- VT inputs configured as 'Voltage Control'
- CT inputs configured as 'Transformer'

Critical hardware failures will result in loss of automatic voltage control. Fascia LEDs will be held on and a corresponding message will be displayed on the front screen in upper case letters. An example of this is shown in Figure 25.

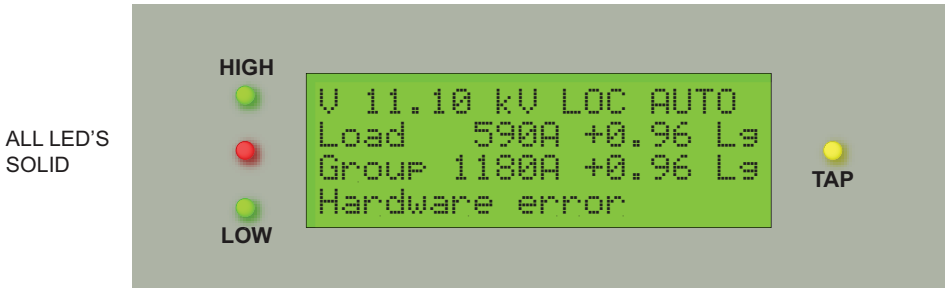


Figure 25 – Relay indications for hardware error

Non-critical hardware failures will not result in the loss of automatic voltage control, but operation may be impaired. No additional fascia LEDs will be held on but a corresponding message will be displayed on the front screen in lower case letters.

6.2 CAN Bus Errors

Each relay on the CAN bus monitors the status of peer units and amends operation as appropriate where there are errors or faults. Relays will use all available data on the CAN bus and indicate when there are problems via messages on the front screen. Possible CAN bus errors are as follows:

- Comms ID clash - transformer ID of two or more units are the same
- Communications error - CAN bus problem

- DAM error - DAM unit alarming
- Comms data missing - Units which were previously transmitting data on the CAN bus are missing

7 Alarms

There are two alarm output relays available:

- Relay Healthy
- AVC Alarm

Output relay statuses are logged and displayed in the ‘Faults’ screens (see section 11.3.3).

7.1 Relay Healthy

The Relay Healthy output relay operates according to the following:

- Energised when the SuperTAPP n+ is powered and functioning correctly
- De-energised when the SuperTAPP n+ is either:
  - Powered down
  - Experiencing a critical hardware failure

The Relay Healthy output has changeover contacts for external indication of the SuperTAPP n+ status (see section 10.2.5 for status outputs).

7.2 AVC Alarm

The AVC Alarm output relay will be energised when the relay experiences any of the following for a period of time which exceeds the alarm time setting:

- Operational state outside ‘Voltage Normal’ in automatic mode of control
- CAN bus errors
- Non-critical hardware failure

The alarm time is configurable with a default setting of 5 minutes. The alarm can be inhibited for low voltage conditions by use of the ‘alarm inhibit’ setting which can be configured between 0% and 80% voltage target (default 80%).

The output relay has a normally open contact for external indication of an operational problem (see section 10.2.5).

8 Application

8.1 Introduction

This section describes each of the features which can affect the target voltage of the relay in accordance with the equation presented earlier:

$$V_{tgt} = V_{basic} + V_{adj} + V_{circ} + V_{LDC} + V_{gen}$$

where

V_{tgt}	=	relay target voltage used for control
V_{basic}	=	relay basic target voltage setting
V_{adj}	=	voltage target adjustments applied via status inputs
V_{circ}	=	circulating current bias voltage
V_{LDC}	=	load drop compensation bias voltage
V_{gen}	=	embedded generator bias voltage*

* available only with an advanced model

All features except the generator voltage bias are valid for the basic model of relay. The generator voltage bias feature is only available on an advanced model (see section 9).

8.2 Basic voltage target - V_{basic}

The relay basic target voltage defines the normal target voltage for the control system and is one of the most fundamental settings in the relay. It is expressed as a percentage, with 100% corresponding to the network nominal voltage.

As an example, if the nominal network voltage is 11 kV and the transformer secondary nominal voltage is 11.5 kV, the correct basic setting is 100% for a target of 11 kV, and NOT 104.5 %. The network nominal voltage must be set correctly in the relay settings.

8.3 Voltage Adjustments - V_{adj}

The voltage target of the relay is affected by remote voltage adjustments applied via digital status inputs or SCADA communications. These adjustments are required for load reduction purposes to assist the transmission network, and are typically applied as separate +3%, -3% and -6% instructions.

Three status inputs are available on the SuperTAPP n+ for this use with added flexibility for different applications. The inputs can be configured to operate in two modes:

- **Fixed** - adjustments are applied as permanent signals and result in fixed changes to the relay basic target voltage while the signals are active.
- **Step** - adjustments are applied as fleeting signals and result in step changes to the relay basic target voltage each time a signal is received.

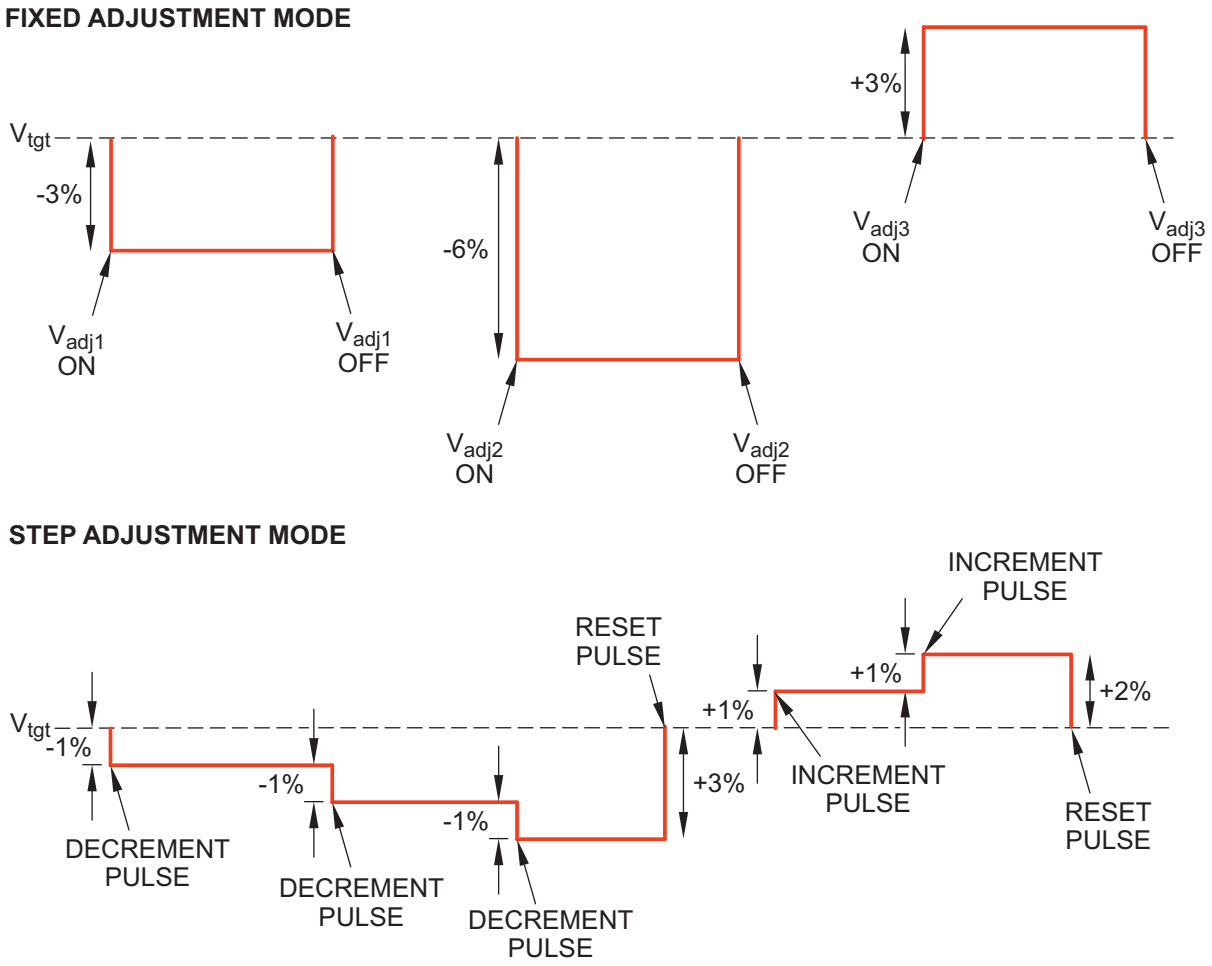


Figure 26 – Voltage adjustments

The operating mode of applied voltage adjustments is configured in the relay settings as 'fixed' or 'step' along with the corresponding values assigned to each of the three status inputs (they are not limited to 3% and 6% only).

In the case of paralleled transformers, any voltage adjustments should be applied to all controlling relays, otherwise voltage errors can result along with circulating current (see next section).

Multiple adjustments can be applied simultaneously and result in a summed adjustment to the voltage target (only valid for 'fixed' adjustments). For example, application of +3% (adjustment 1), -3% (adjustment 2) and -6% (adjustment 3) results in a change to the target voltage of -6%.

See section 10.2.7 for more information relating to status inputs.

8.4 Circulating Current - V_{circ}

It is common practice to operate transformers in parallel for security of supply. Paralleled transformers are usually at the same substation, but not always. Some network operators operate transformers in parallel across the network.

If the open circuit terminal voltages of paralleled transformers are not identical, a circulating current will flow between them (at a site or across the network). This current will be highly reactive since the transformers are essentially inductive. Figure 27 shows two paralleled identical transformers at a site,

T1 and T2, on different tap positions with corresponding vector diagrams. For clarity, load current is ignored (transformers energised but not on load). T1, being on a higher tap position, will attempt to produce a higher output voltage than T2 and therefore exports circulating current into T2. The bus-bar voltage, V_{bus}, will be the average output voltage of the transformers.

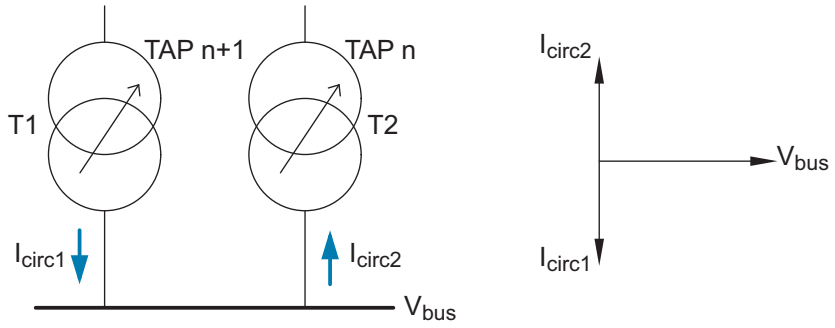


Figure 27 – Transformer circulating current

Any voltage control relay must include a method to maintain the tap position to the point where circulating current is minimised, otherwise the tap changers will drift apart and, while the voltage will be the average of their terminal voltages, a high amount of circulating current will flow between them. This will cause an unnecessary power loss within the transformers and the network, reducing their useful capacity and their efficiency. In a worst case this may lead to transformers tripping on high winding temperature or directional overcurrent, and a complete loss of voltage control.

The SuperTAPP n+ employs the 'enhanced TAPP' method to calculate the circulating current (site and network components) and convert it into a corrective voltage bias, V_{circ}. The voltage bias modifies the target voltage of the relays in order to promote tap changer operations which will reduce the circulating current to a minimum.

As can be seen from equation 1, negative V_{circ} (an export of circulating current), as seen by T1 in Figure 27, decreases the relay target voltage, making the relay tend to tap down. Positive V_{circ} (an import of circulating current), as seen by T2 in Figure 27, increases the effective target voltage, making the relay tend to tap up.

The site circulating current is calculated using the 'true circulating current' method, which is dependent on the individual transformer load and the summed load of paralleled transformers. The network circulating current is calculated using the 'TAPP' method (Transformer Automatic Paralleling Package) which is dependent on the group load and target power factor setting of the relay (typically 0.96 lagging or so).

The circulating currents are then converted into V_{circ} using the following relay settings:

- Transformer rating
- Firm capacity
- Transformer % impedance
- Sensitivity factor for network circulating current*

*the sensitivity factor is included to reduce the errors associated with a fluctuating load power factor (for example due to embedded generation). The default setting is 10% as a safety margin.

The calculations shown above depend on the group load and therefore the use of CAN bus communications. It may be that CAN bus communications is not possible, in which case circulating current will be calculated using the TAPP mode, and the above-mentioned sensitivity factor should be set to 100%. Alternatively, relays may directly measure the group load using a special CT type (see section 9.2.1 for more details of the various types of CT function available).

The calculated values for circulating current and the corresponding voltage bias, V_{circ}, can be viewed in the instrument screens (see

8.5 LDC - V_{LDC}

Load drop compensation (LDC) is used to offset voltage drops across a network caused by load current, as shown in Figure 28.

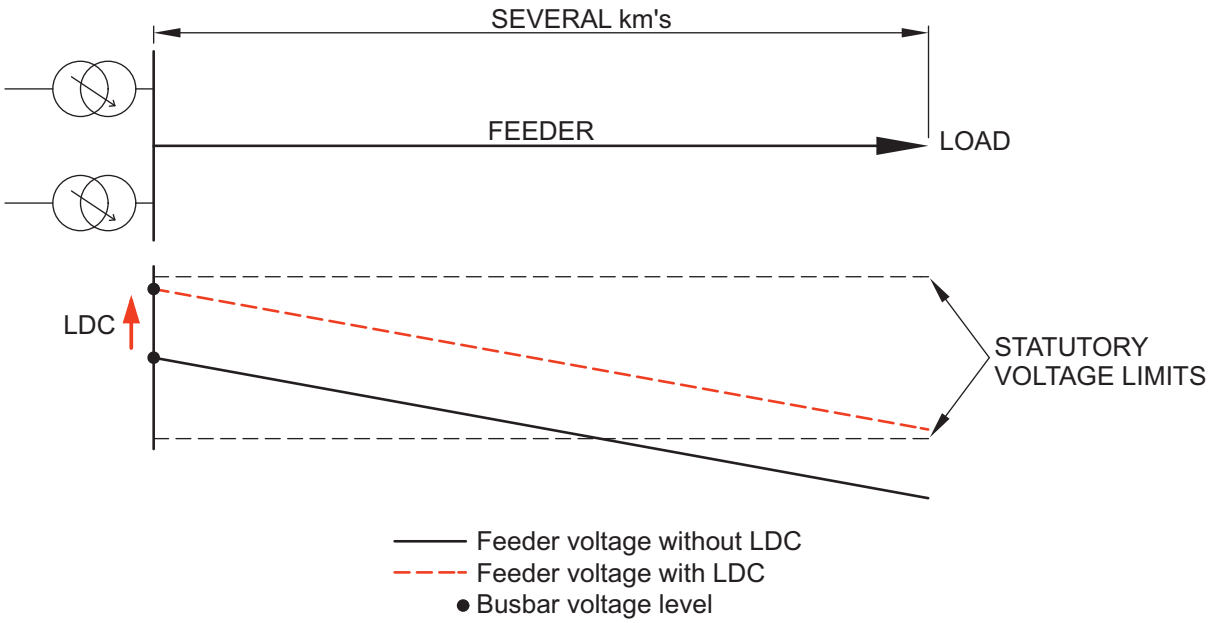


Figure 28 – Load drop compensation (LDC)

The voltage bias for LDC (V_{LDC}) is applied in proportion to the load current and is expressed as a percentage boost at full load (firm capacity setting). For example, an LDC setting of 10% means that at full load the voltage boost applied to the relay will be 10% of nominal. At half load, the boost will be 5%.

In order that the voltage is boosted for LDC, the bias to apply to the relay is positive (see equation 1). LDC is calculated using the following:

- LDC setting
- Group load
- Target power factor (relay setting)
- Firm capacity (relay setting)

LDC is applied according to the assumed load power factor to minimise the effects of purely reactive network components such as capacitor banks, heavy industrial loads etc. The effect of this is shown in Figure 29.

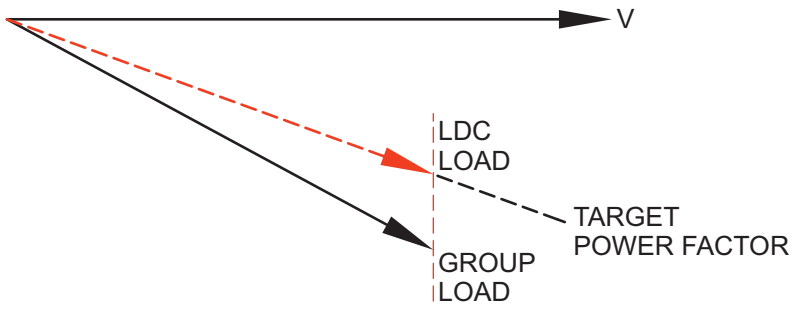


Figure 29 – Application of LDC

The applied LDC bias is capped at the setting level; it cannot be more than the setting level even if the group load increases to above the firm capacity setting level.

For situations where the group load is negative, e.g. where there is an excess of connected generation and the transformers are in reverse power flow, the LDC response is dependent on the relay setting 'Reverse LDC' which gives the following options:

- OFF – LDC applied is 0%
- ON – Negative LDC applied as per 'forward flow' calculations

The LDC response is shown in Figure 30.

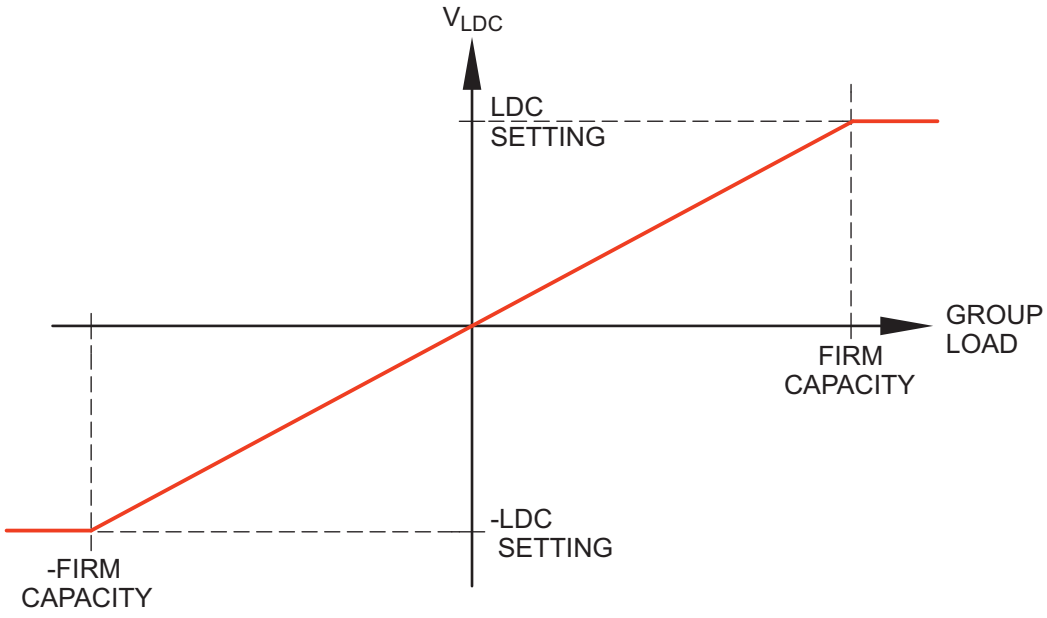


Figure 30 – LDC response

The advanced relay model has extra LDC settings available to provide more flexibility for reverse power such as target power factor and capping levels (see section 9).

9 Application - Advanced Model Only

9.1 Introduction

The previous application section described features which are available on a basic model (which are also available on an advanced model). This section describes features which are only available on an advanced relay.

9.2 Multiple Analogue Inputs

The advanced model of relay has extra VT and CT inputs available to provide enhanced voltage control for all application complexities. Normally, one CT input is used for measurement of the transformer load which means that each advanced relay has two spare CT inputs for various uses. All measurement data is transmitted on the CAN bus and made available to all other connected relays.

In order to make use of the extra VT and CT inputs (i.e. upgrade from a basic model to an advanced model), an activation code must be purchased from Fundamentals Ltd and entered into the relay settings.

The extra inputs are used for the following:

1. Feeder current measurements
2. Double-secondary winding transformer measurements

These applications are considered in turn in the following sections.

9.2.1 Feeder Current Measurements

Introduction

Conventional voltage control uses the measured transformer current, usually via the LDC CT, for load drop compensation and/or circulating current control. These functions have been discussed in sections 8.4 and 8.5 respectively.

Modern networks have increasing levels of electrical plant connected which can compromise conventional voltage control due to the injection of real and reactive power (for example embedded generation, capacitor banks and other reactive support devices). Different types of highly reactive load can also add to voltage control problems (for example heavy industrial loads which are on in the day and off at night).

Normally, these items of ‘problem plant’ are confined to individual outgoing feeders, while other feeders are unaffected. Despite this, the voltage control effect is experienced by all feeders. The relay has functions available to solve these problems, which rely on the implementation of extra current measurements on the outgoing feeders which have connected ‘problem plant’.

Implementation

The feeder current measurements are facilitated by feeder protection CTs. In order that this does not compromise the protection scheme, very low burden interposer CT’s are used to interface with the SuperTAPP n+ relay. These CT’s are 1000:1 ratio wedding ring type with burden < 0.05 VA. The CTs are described in detail in section 10.2.3.

As discussed earlier, all relay measurements are transmitted on the CAN bus to make them available for peer units. Functions which make use of these measurements must be applied in the same way to all relays in the group, otherwise the desired effects will not be realised and voltage errors can occur.

Special attention therefore needs to be given to relays which are configured for feeder current measurements so that the data can be available even when the transformers to which they are connected are switched out (e.g. for maintenance), namely:

1. Power supply

   The relay must be powered to continue transmitting measurement data. Normally the auxiliary AC supply for tap changer control is used to power the control relays and this may be disconnected if the transformer is switched out, so an alternative is required. The best solution is to use the DC supply (if available) to power the relay. The SuperTAPP n+ has a flexible AC/DC input for this use (range is 90 – 240 V AC/DC).

2. Voltage reference.

   The relay uses the VT input as a reference for calculation of real and reactive components of current (see section 4.3). The second VT input of the relay can be configured to use a VT from another transformer in the group as a voltage reference when the main VT input is lost due to a transformer switch out. This will be considered in detail in section 9.2.1, ‘VT Switching’.

Definitions

The important relay definitions are as follows:

- Measured currents – transformers and feeders.
- Non-measured load – sum of the load on feeders which are not being measured.

These values can be understood by reference to Figure 31 which shows an application with feeder measurements on two of the six feeders.

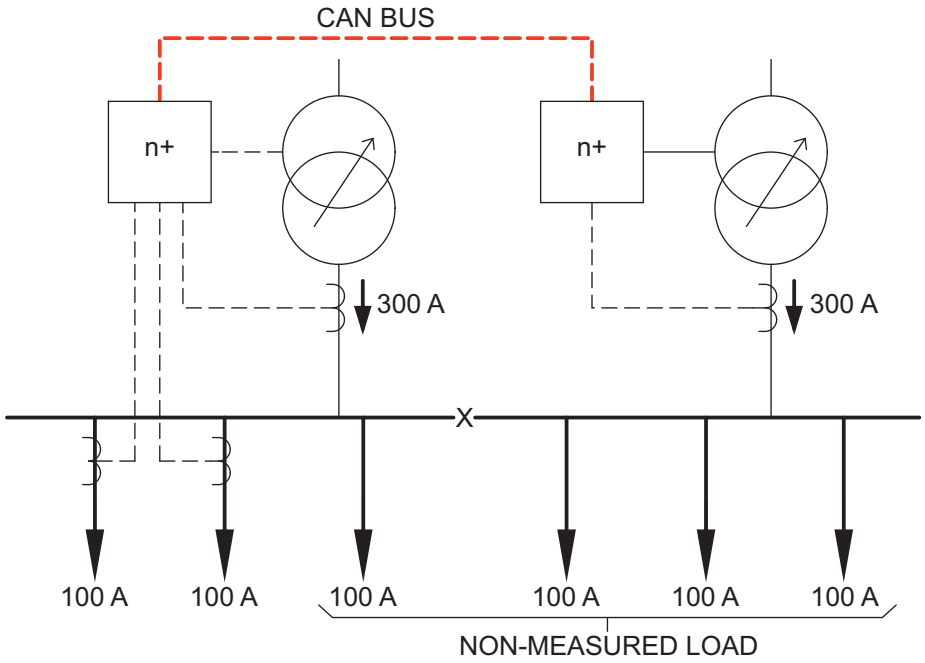


Figure 31 – Definition of non-measured load

In this case both relays would show the following values in the instruments screens (see section 11.3.1):

Summed transformers	=	600 A
Summed feeder measurements*	=	200 A
Non-measured load	=	400 A

*this data will be presented according to how the CT inputs are configured (see below).

Each CT input used for feeder current measurement must be configured in the settings for a specific use. There are many uses to choose from, but broadly they can be split into three types, relating to:

1. Embedded Generation.
2. Reactive Sources / Loads.
3. Special Applications.

Each of these types is described in detail in individual sections below.

Embedded Generation

Embedded generation is defined here as generation of any type connected to the network which the transformer is supplying. The generation can be connected directly to the busbar via one or more dedicated feeders, or remotely to one or more outgoing feeders. In either case the embedded generation can cause the following voltage control issues:

1. Reduction in the applied LDC due to reduced transformer current.
2. Voltage rise along feeders to the point of connection when in reverse power flow (i.e. when the generation exceeds the load on the feeder).
3. Voltage error incurred by inaccurate network circulating current control due to power factor variations on the transformer current.

In order to solve the above problems the relay has functions available which utilise feeder current measurements:

1. Accurate LDC based on the ‘true’ group load. With generation present the summed transformer currents do NOT represent the group load (see figures 32 and 33 below). The relay can determine generation output(s) based on feeder current measurements and use it to calculate the ‘true’ group load.
2. Generation compensation – V_{gen} in equation 1(section 4.4.1). This is a reduction in relay target voltage in proportion with calculated generation output levels:

   $V_{gen} = [\sum(I_G)/\text{Rating}] \times \text{Genbias}$

   where

$\sum(I_G)$	is the measured/calculated generation output (Amps)
Rating	is the maximum generator output rating (Amps)
Genbias	is the %voltage reduction to target at full generator output.

3. Enhanced TAPP circulating current control using the ‘true’ group load.

All of the above-mentioned functions rely on the real-time calculation of the ‘true’ group load and the generation output. There are two methods for this in respect of how the generation itself is connected and how the corresponding feeder current measurement inputs are configured in the relay:

1. Direct generator connection – CT input configured as ‘generator’.

2. Indirect generator connection – CT input configured as ‘generator feeder’.

Direct Generator Connection

An example of this application is shown in Figure 32 where two transformers supply a network via 6 feeders and a generator connected directly to the busbar. There is one voltage control relay per transformer, each of which uses one VT input for voltage measurement and one CT input for transformer current measurement. One of the relays also uses a CT input for the generator measurement. All measurement data is available to all relays connected on the CAN bus.

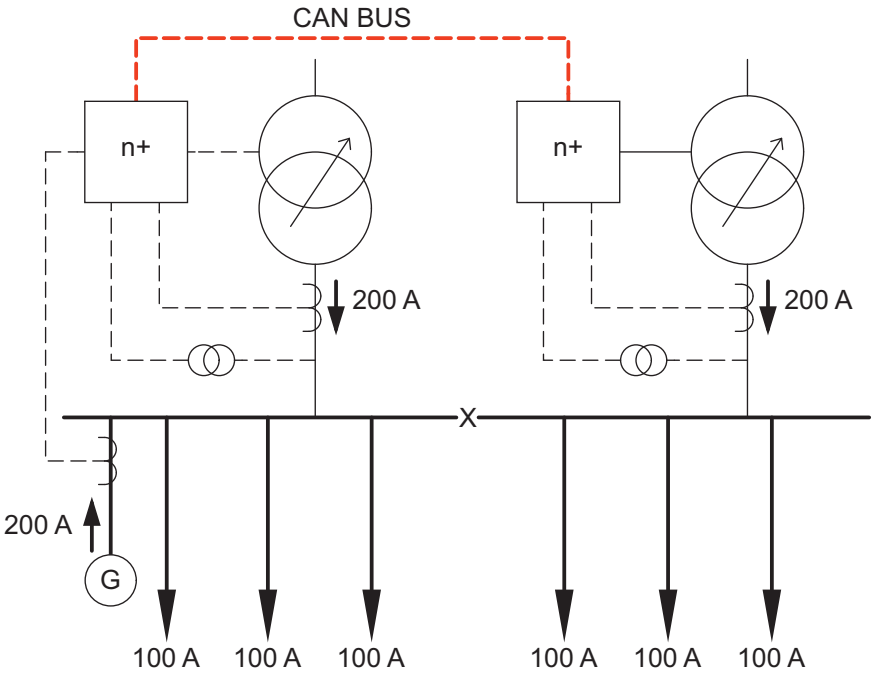


Figure 32 – Direct generation connection

Relay 1 and Relay 2

Transformer Current	=	200 A
Summed Transformer Currents	=	400 A
Summed Feeder Measurements	=	-200 A
Non-Measured Load	=	600 A
Generator Output	=	200 A
Group Load	=	600 A

If the bus section is open, the situation changes* as follows:

Relay 1

Transformer Current	=	100 A
Summed Transformer Currents	=	100 A
Summed Feeder Measurements	=	-200 A
Non-Measured Load	=	300 A
Generator Output	=	200 A
Group Load	=	300 A

Relay 2

Transformer Current	=	300 A
Summed Transformer Currents	=	300 A
Summed Feeder Measurements	=	0 A
Non-Measured Load	=	300 A

Generator Output	=	0 A
Group Load	=	300 A

* the group ID of the relays must change to reflect the new configuration (see section 10.2.7 for 'alternative settings').

In order to accommodate all applications to include any number of transformers and generator connections, the above calculations can be summarised as follows:

Summed Transformer Currents	=	$\sum(I_{Tn})$
Generator Output	=	$\sum(I_G)$
Group Load	=	$\sum(I_{Tn}) + \sum(I_G)$

Indirect Generator Connection

An example of this application is shown in Figure 33 which shows the same network as presented in Figure 32 but with the generator connected remotely (e.g. several km's away) to one of the feeders (called the 'generation feeder').

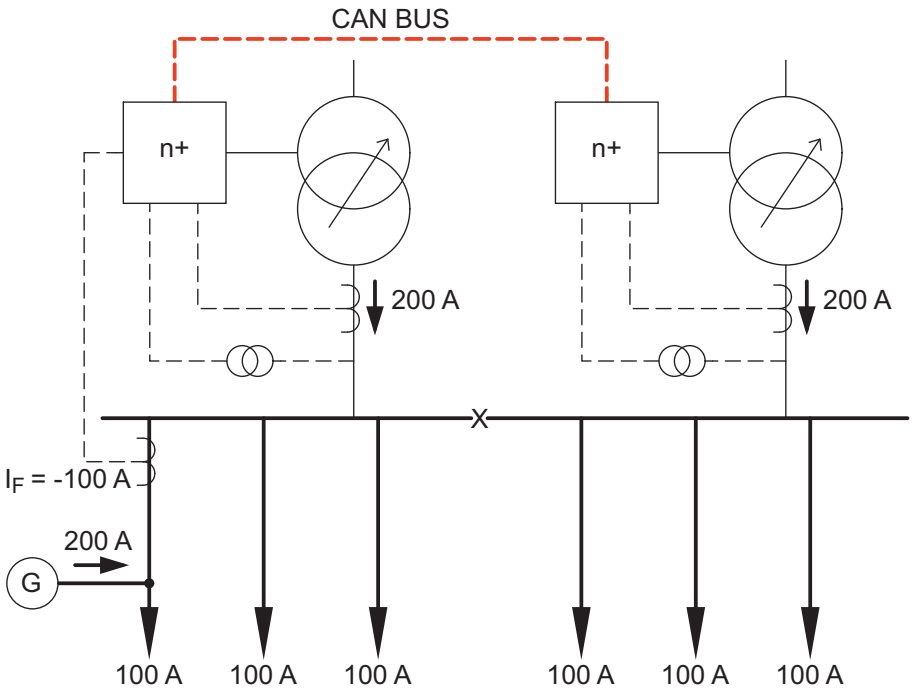


Figure 33 – Indirect generation connection

The generator feeder has connected load and generation but the feeder current measurement, I_F, cannot discern between them. The example network shows this where the measured feeder current is -100 A, with 100 A of load and 200 A generation present.

The relay has a generation estimation function which can calculate load and generation present on the network. The generator estimation function depends on the following:

- Current Measurements
  - Summed Transformer
  - Generator Feeders
- Load Ratio

The Load Ratio is a relay setting which is expressed as a percentage and defined as follows:

Load Ratio = 'true' load on generation feeders / load on 'non-measured' feeders

The load ratio of the example network shown in Figure 33 is 20%. (100 A / 500 A).

The relevant calculations for the two relays shown in the example network are as follows (all data presented in the relay instruments to aid troubleshooting):

Relay 1 and Relay 2

Transformer Current	=	200 A
Summed Transformer Current	=	400 A
Generator Feeder Current	=	-100 A
Non-Measured Load	=	500 A
Estimated Load	=	100 A
Estimated Generation	=	200
Group Load	=	600 A

If the bus section is open, the situation changes* as follows:

Relay 1

Transformer Current	=	100 A
Summed Transformer Current	=	100 A
Generator Feeder Current	=	-100 A
Non-Measured Load	=	200 A
Estimated Load	=	100 A
Estimated Generation	=	200
Group Load	=	300 A

Relay 2

Transformer Current	=	300 A
Summed Transformer Current	=	300 A
Generator Feeder Current	=	0 A
Non-Measured Load	=	300 A (but this is dependent on a new Load Ratio of 0% according to 'alternative settings' †)
Estimated Load	=	0 A
Estimated Generation	=	0
Group Load	=	300 A

* the group ID of the relays must change to reflect the new configuration (see section 10.2.7for 'alternative settings').

† in the event of a network configuration change or fault, it is possible to switch the relay to use 'alternative settings'. This gives added flexibility so that the relay can be configured appropriately for abnormal operating conditions. Some examples of how the relay could be configured for abnormal situations are as follows:

- Revert to 'safe' operating mode where feeder current measurements and generator estimation are ignored
- Adopt a new load ratio for a specific configuration
- Switch the relay to non-auto mode ('tap lock')

In order to accommodate all applications to include any number of transformers and generator connections, the above calculations can be summarised as follows:

Estimated Load	=	Non-Measured Load x Load Ratio
Estimated Generation	=	Estimated Load – Generator Feeder Current
Group load	=	Non-Measured Load x (1 + (Load Ratio/100))

The load ratio can be determined from historical load data or from direct measurements. If historical data is used, the load ratio should be taken as an average value from a period of time over which the

extent of seasonal variations can be observed. If direct measurement is used to determine the load ratio it must be ensured that the generation is not running so that the measurement represents the 'true' load.

Once the load ratio has been calculated it is configured into the relay settings. It is clear that the actual load ratio will vary over time due to seasonal variations and network events (outages, faults etc.). For this reason, the relay settings should be regularly checked to ensure that errors associated with these variations are kept to a minimum.

The accuracy of the generation estimation algorithm will vary throughout a year and across a network. Each application will demand an extent of network analysis to optimise the system and minimise errors. The estimation errors can be eliminated if generator output levels are measured at the point of connection and made available at the substation SuperTAPP n+ system via an ENVOY unit as shown in Figure 34.

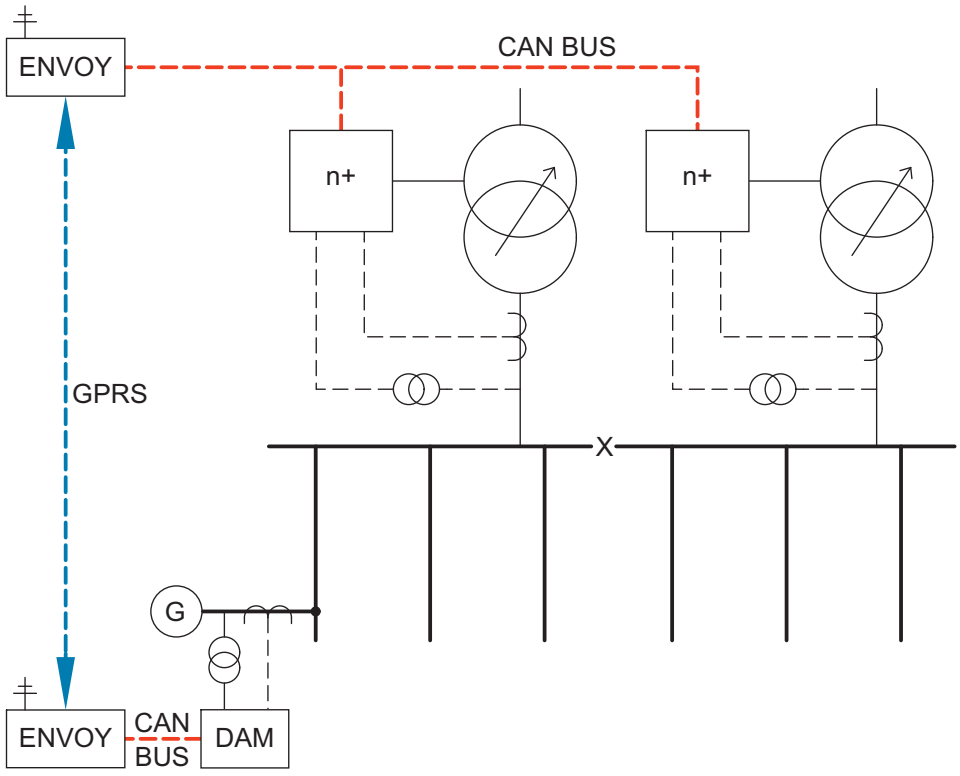


Figure 34 – Remote measurements with ENVOY

Generation estimation can be adversely affected by 'troublesome loads' connected to the non-generation feeders. The effect can be mitigated by the use of functions associated with reactive loads and sources which are described in the next section.

Reactive Loads and Sources

The presence of a load which varies significantly in power factor from the 'normal' (target) system power factor can cause the following issues:

1. Voltage errors incurred by inaccurate LDC.
2. Voltage errors incurred by inaccurate network circulating current control.
3. Generator estimation errors.

Examples of such loads are capacitor banks, heavy industrial loads and embedded generators. Figure 35 shows the power factor effect of a capacitor bank.

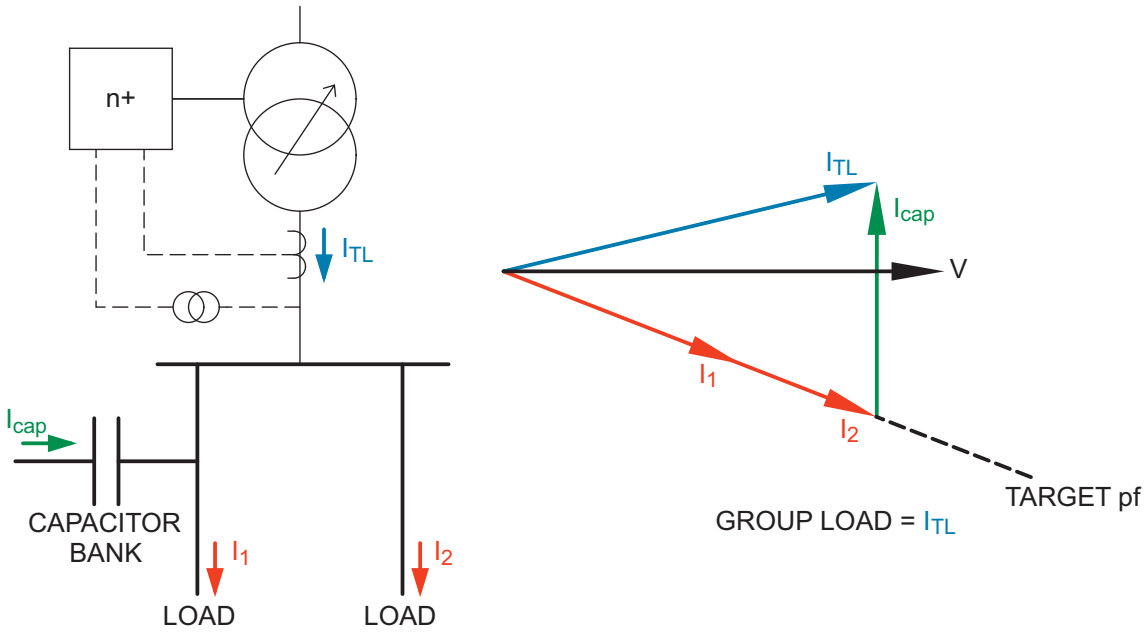


Figure 35 – Power factor effect of capacitor bank

In order to solve these problems the relay has functions available which utilise feeder current measurements to calculate the 'true' load power factor as accurately as possible and thus minimise errors. There are options for how these current measurements are configured and used in the relay:

1. Excluded Load.
2. Corrected Load.

Excluded Load

The simplest solution to power factor problems is to exclude the 'troublesome' load completely from the system as shown in Figure 36. The drawback of doing this is a reduced group load, and care needs to be taken where LDC is applied so that full boost is applied to the relay at an amended site capacity (see earlier section 8.5 for a description of how LDC is applied).

If the relay is configured for generator estimation, the load ratio calculation must exclude feeders configured as excluded loads.

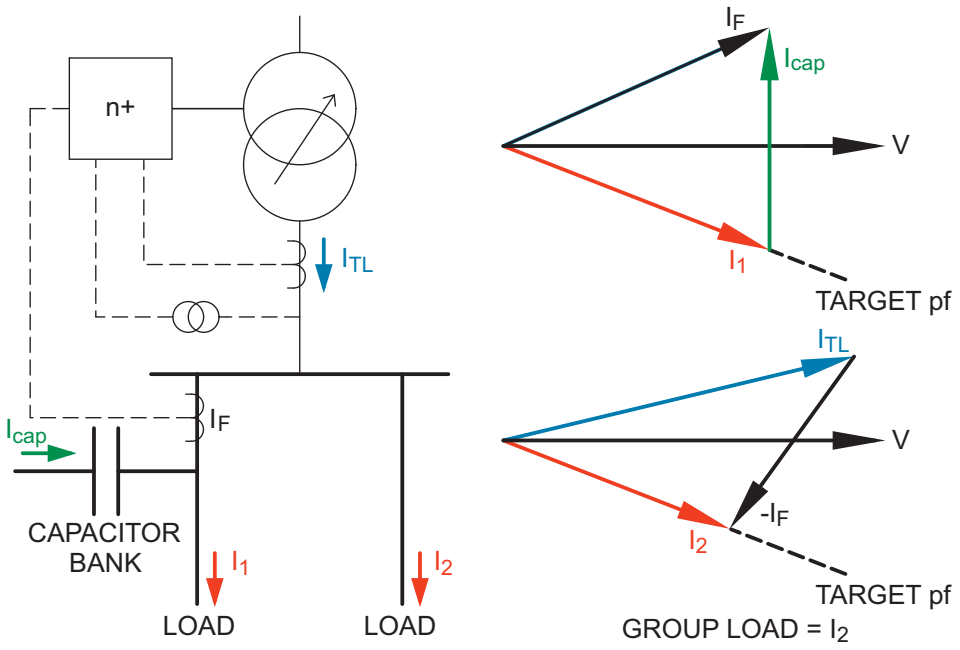


Figure 36 – Load exclusion

Corrected Load

This type is similar to the excluded load type considered above, except that instead of 'dumping' the measured current, the measurement is 'adjusted' to the relay target power factor as shown in Figure 37.

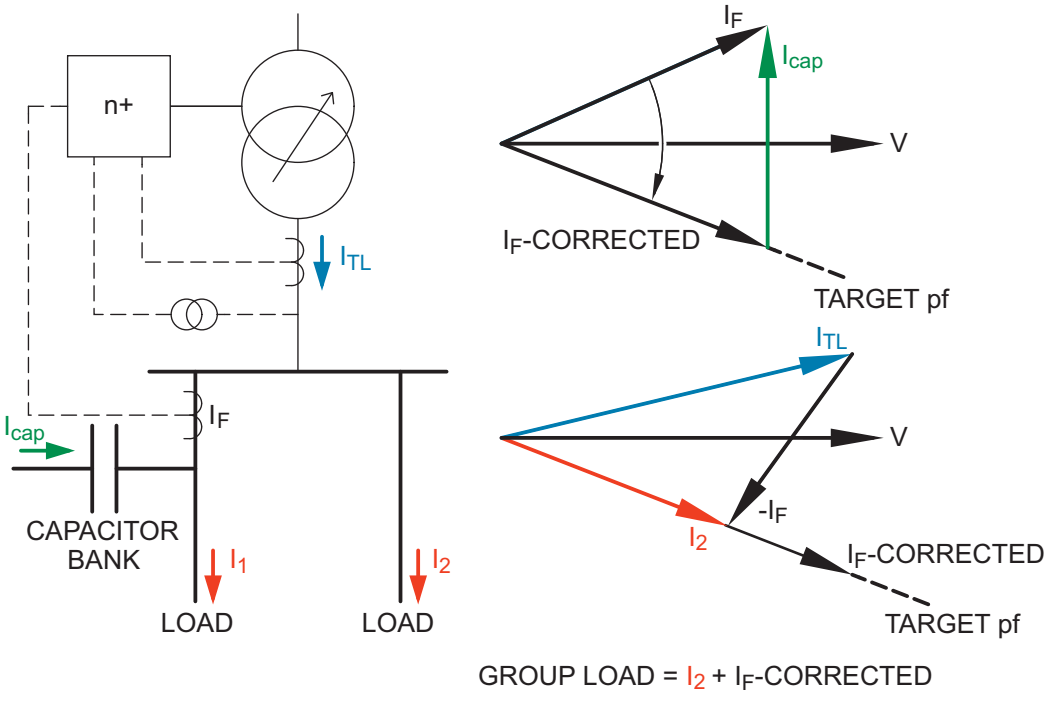


Figure 37 – Load correction

In this way, the voltage accuracy of the relay is not impaired by the troublesome load, and also the load information (if any) is maintained for LDC purposes.

If the relay is configured for generator estimation, the load ratio calculation must exclude feeders configured as corrected loads.

Special Applications

There are a number of functions available for applications which are somewhat unusual and seldom experienced, but further extend the flexibility offered. These functions relate to the use of the extra current measurements in the following configurations:

1. Extra Transformer
2. Included Load
3. Monitor

Extra Transformer

This type is used to where it is not possible to calculate the summed loads using the CAN bus system (e.g. due to distances or lack of cable ducts/trenches, or where the SuperTAPP n+ relay is operating in parallel with another type of relay).

The ‘extra transformer’ measurement enables the summed load calculation as shown in Figure 38.

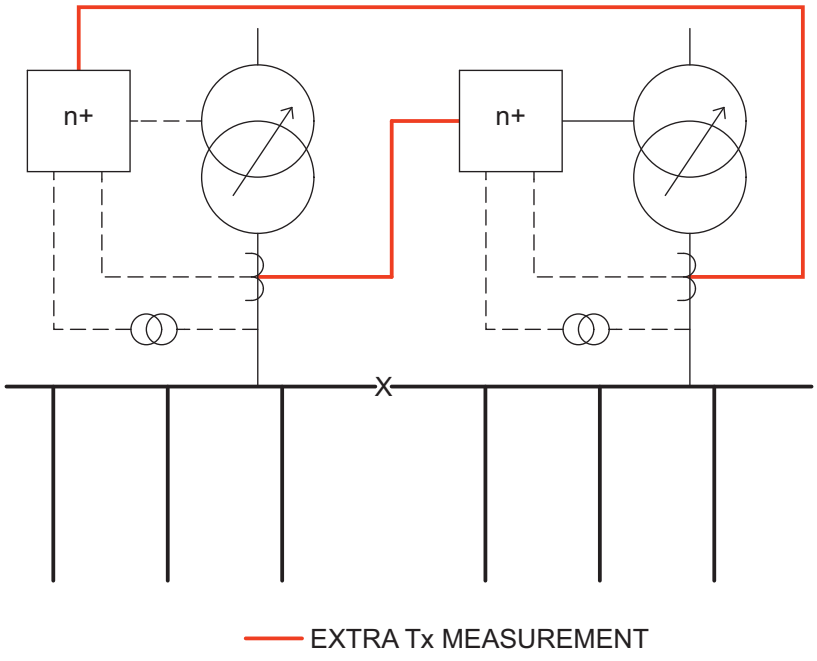


Figure 38 – Extra transformer current measurement

Included Load

As presented earlier, the actual load on generator feeders can be calculated using the non-measured load and the load ratio setting according to the following for the example network shown in Figure 33:

Estimated Load = Non-Measured Load x Load Ratio

In some situations it may be that the non-measured load is not truly representative of the load on the generator feeders. An alternative is to select the most representative feeder(s) to use to calculate the load on generator feeders. This is shown in Figure 39 for the same example network.

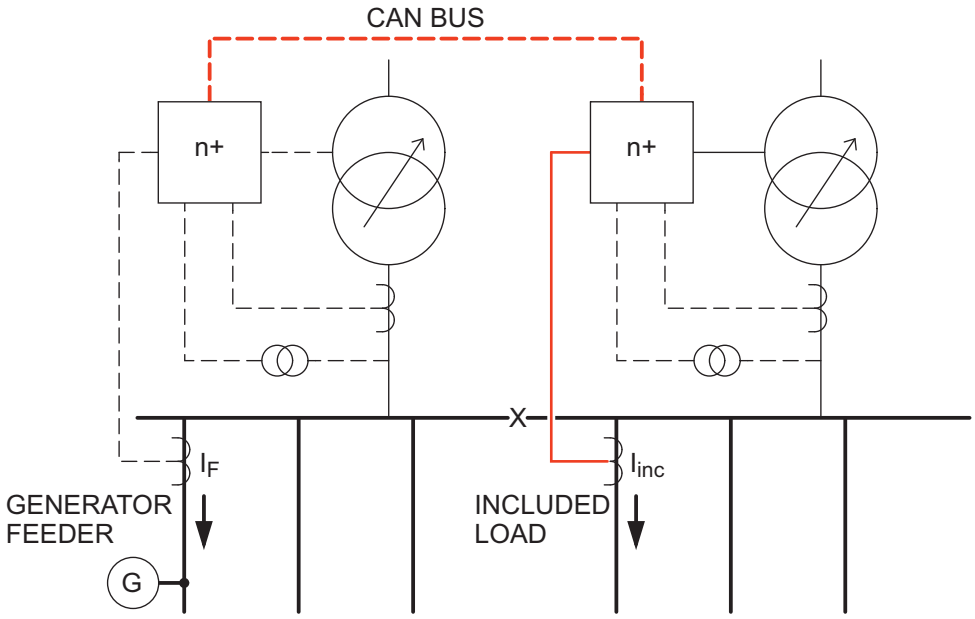


Figure 39 – Load inclusion

The actual load on the generator feeder is now as follows:

$$I_{F\text{-}LOAD} = I_{inc} \times \text{Load Ratio}$$

This approach gives added flexibility to the application of generator estimation.

Monitor

This type is used for monitoring purposes only. The CT input measurements are displayed but are not used for any operational purposes.

VT Switching

Each current measurement requires a voltage reference for calculation of the real and reactive components (see section 4.3). Normally this comes from the VT on the transformer which the relay uses for regulation.

Relays which are configured for feeder current measurements require an alternative voltage source to use as a reference for when the transformer to which it is connected is switched out (for maintenance etc.) and the regulation VT input is lost. It is possible to use the VT from another transformer (if available) for this use, where it is wired to the second VT input of the relay and configured as 'voltage reference'. If no back-up voltage source is available, the feeder current measurement information will be lost during the transformer outage and a corresponding error message and alarm will result.

Figure 40 shows an example scheme where each relay uses the VT from the paralleled transformer as a back-up voltage reference. Table 3 shows how the voltage inputs are configured on each relay.

Table 4 shows which voltage source is used on each relay according to the transformer status.

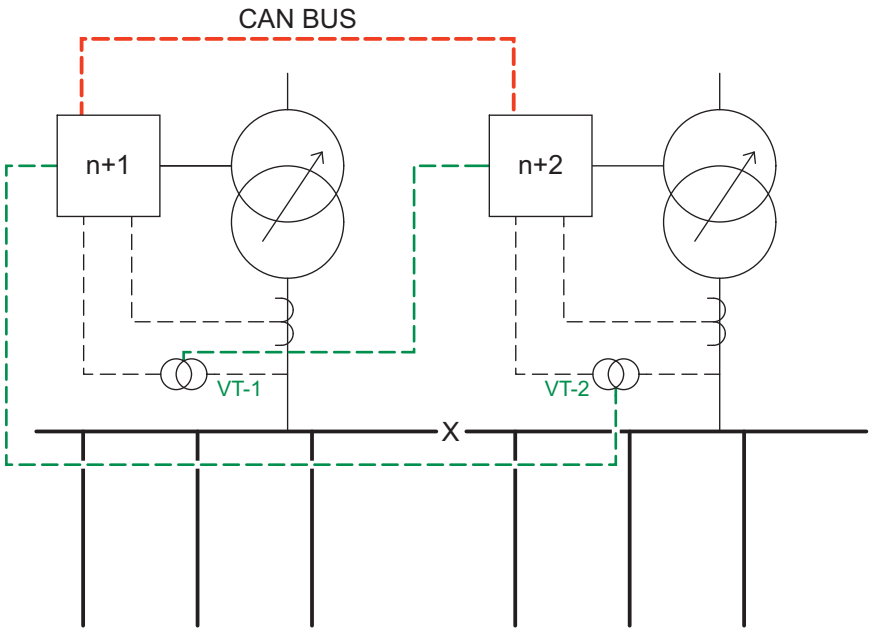


Figure 40 – Extra VT input from paralleled transformer

Table 3 – VT input configurations

	Relay 1		Relay 2	
	VT Connected	**VT Use**	**VT Connected**	**VT Use**
VT Input 1	VT-1	Voltage Control	VT-2	Voltage Control
VT Input 2	VT-2	Voltage Reference	VT-1	Voltage Reference

Table 4 – VT used for voltage reference

Active Transformers	Relay 1 Voltage Reference	Relay 2 Voltage Reference
T1 & T2	V_{VT-1}	V_{VT-2}
T1	V_{VT-1}	V_{VT-1}
T2	V_{VT-2}	V_{VT-2}

The voltage level at which the voltage source switches from one VT input to another is 80% nominal.

9.2.2 Double-Secondary Winding Transformers

Since the tap changer is normally located on the HV side of the transformer (single winding), regulation of transformers with two secondary windings requires the calculation of the average of the measured secondary voltages and the sum of the loads on each winding. Two VT inputs and two CT inputs are therefore required for control of double-secondary winding transformers, as shown in Figure 41.

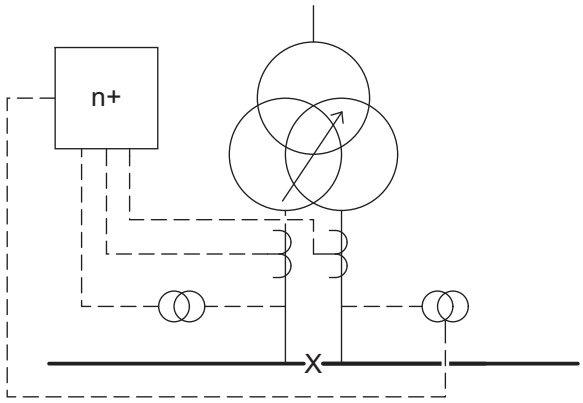


Figure 41 – Double secondary winding transformer

In order to implement voltage averaging, each VT input must be configured as 'voltage control' and each CT input as 'transformer' in the settings. The calculated average voltage is used as V_{VT} to compare with the relay target voltage as shown earlier in Figure 5. The summed transformer load is used to calculate the group load and in turn for LDC and circulating current functions as discussed in sections 8.4 and 8.5.

Where the measured voltage on a VT input falls below 80% nominal voltage (for example in the event of a fuse failure), the relay will automatically revert to using the remaining VT for voltage control. Voltage averaging will resume once the other VT input recovers back to above the 80% level.

The relay will alarm if the voltages as measured by the two VT inputs differ by more than 10% in magnitude or 20°in angle.

9.3 Advanced LDC

As already discussed in section 8.5, Load drop compensation (LDC) is a voltage boost used to offset voltage drops across a network caused by load current. Where the load on the transformer is in reverse power flow (due to embedded generation), it may be beneficial to apply a voltage reduction as 'reverse LDC'. The basic relay model can be configured to apply reverse LDC in such a way that mirrors the forward power flow response (see Figure 30).

The advanced relay model has extra LDC settings available to provide more flexibility for reverse power. The target power factor which the relay uses to calculate the LDC response can be modified for reverse power as shown in Figure 42. The relevant setting is called 'reverse power factor'.

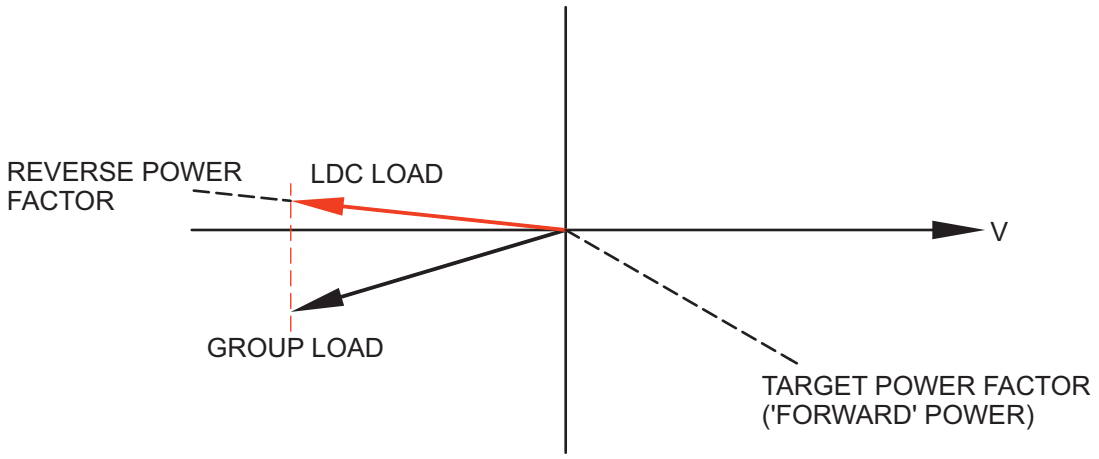


Figure 42 – LDC for reverse power

Other settings for reverse LDC are ‘max reverse load’ and ‘reverse LDC level’. The ‘max reverse load’ defines the group load level at which the ‘reverse LDC level’ is applied. These settings allow the reverse LDC response to differ to the ‘forward’ LDC response, as shown in Figure 43.

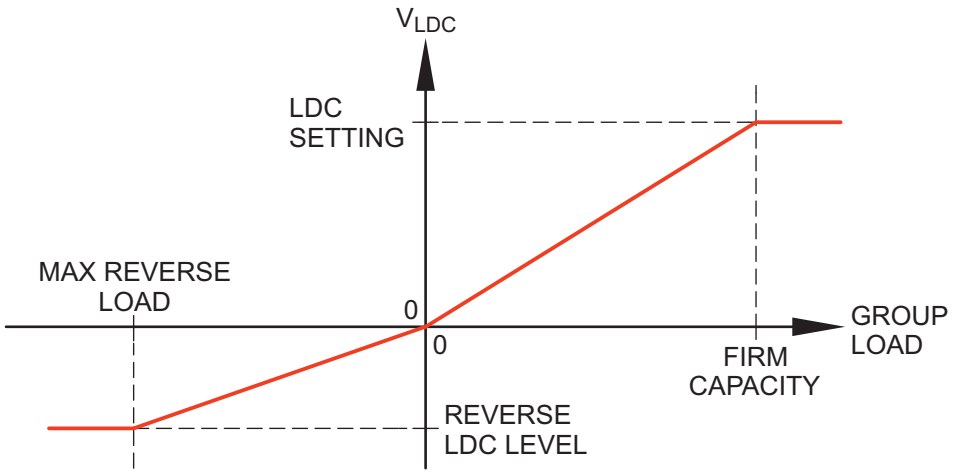


Figure 43 – Reverse LDC response

10 Specification

10.1 Hardware

The relay is housed in a 1 mm mild steel anodised case finished in an over baked powder coating. A transparent cover is fixed to the front of the relay for normal operation. With the cover in place, the user can observe fascia indications and read the LCD, but can also push the control knob to view some instruments. Where settings need to be amended or more detailed instruments viewed, the user must remove the cover such that the control knob may be turned.

Figure 44 to Figure 47 show the relay dimensions in front, rear, plan and side views.

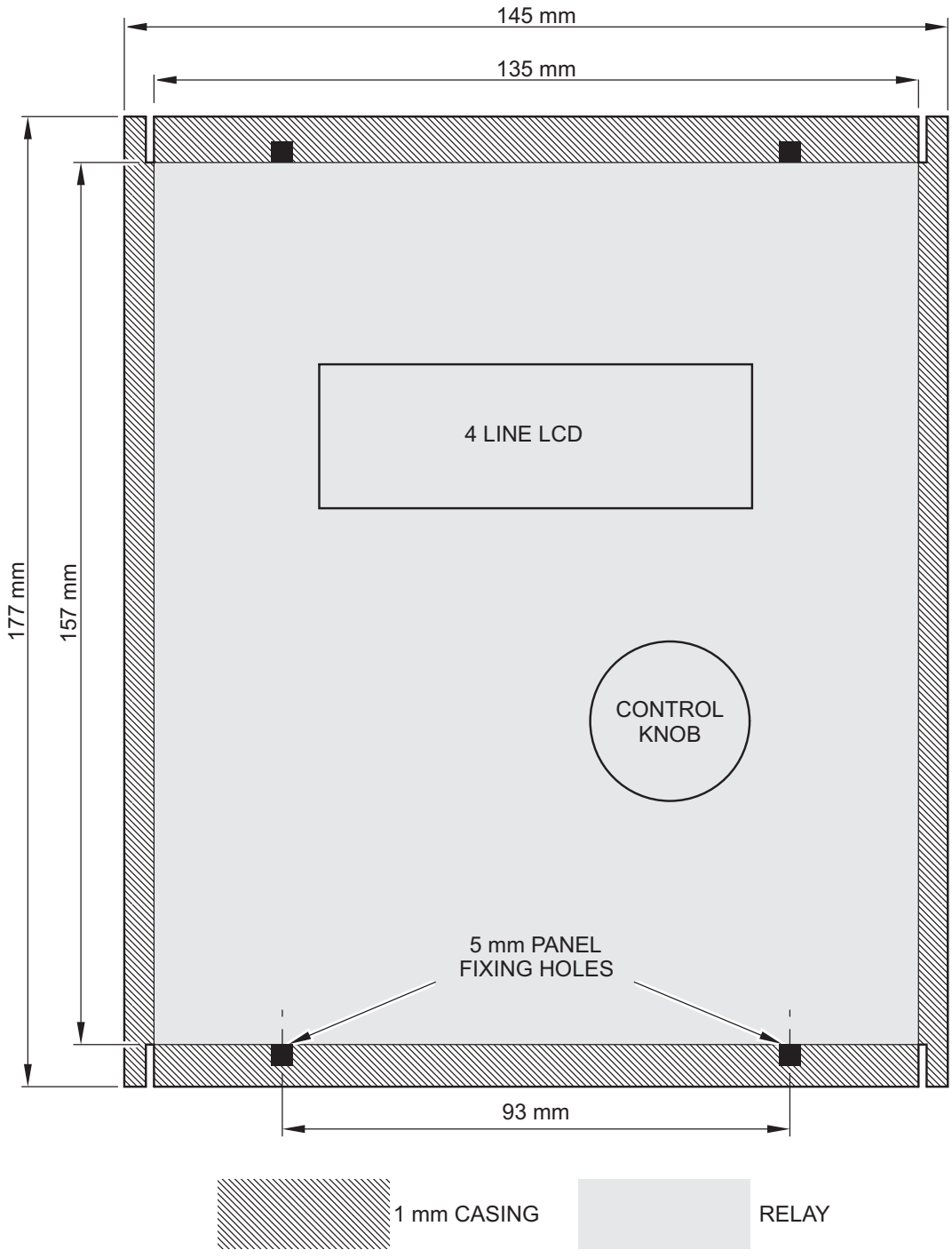


Figure 44 – Relay dimensions – front view

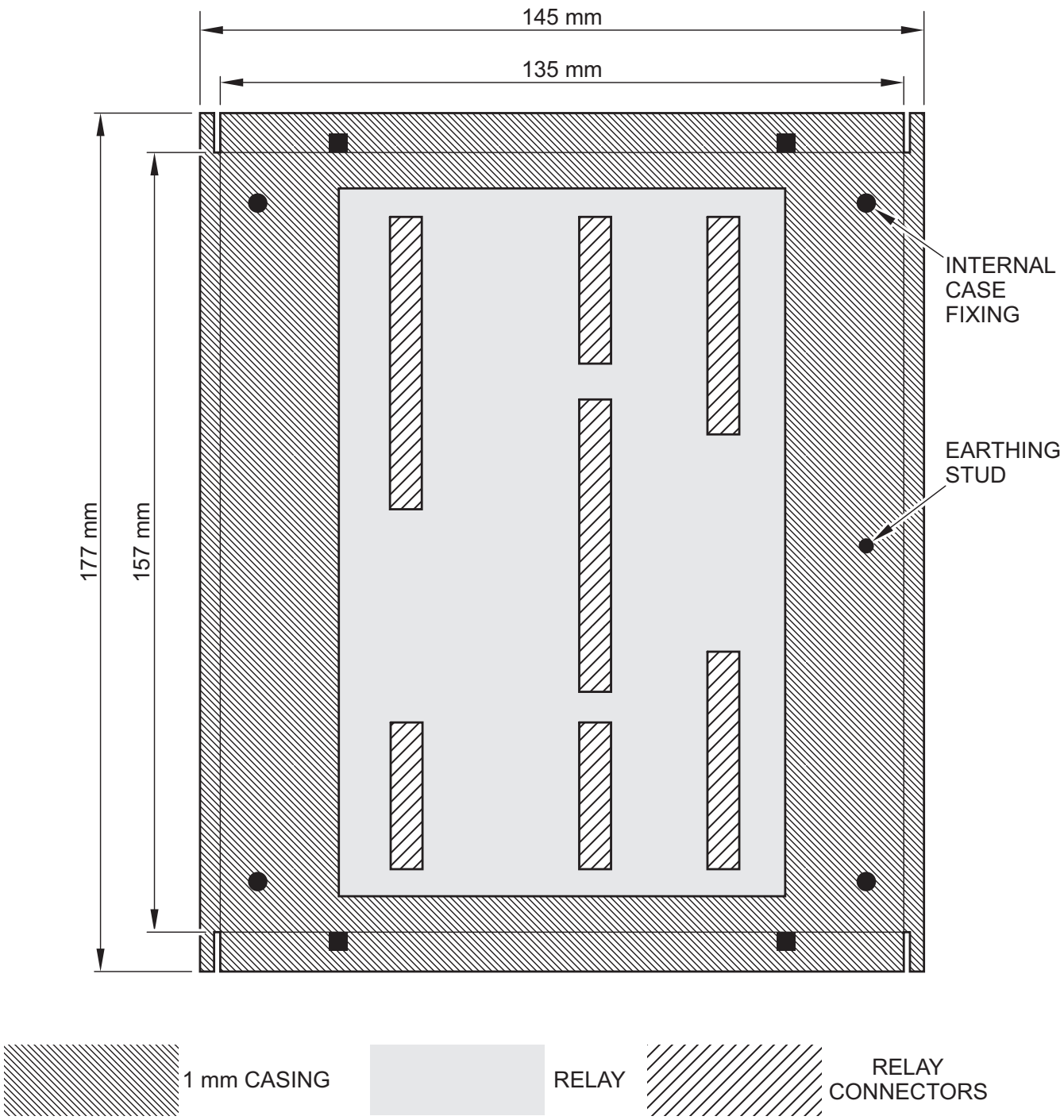


Figure 45 – Relay dimensions – rear view

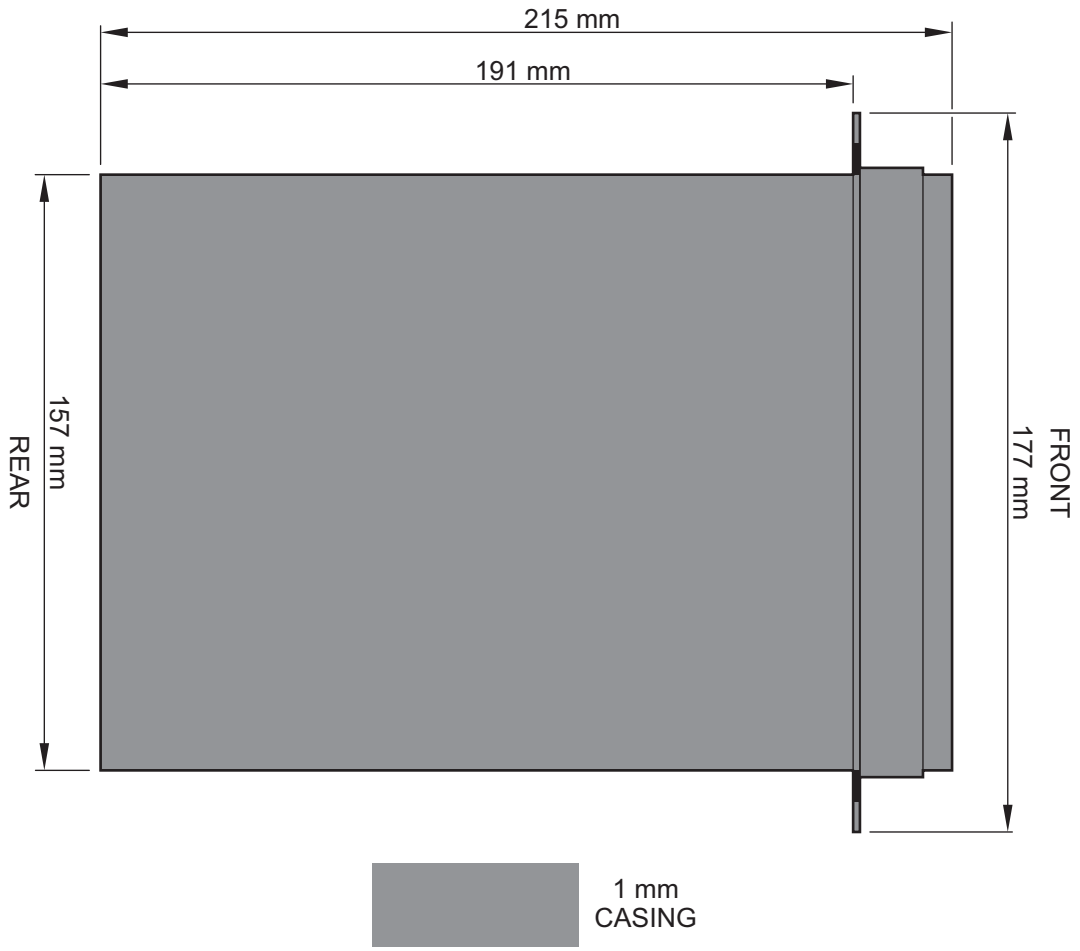


Figure 46 – Relay dimensions – side view

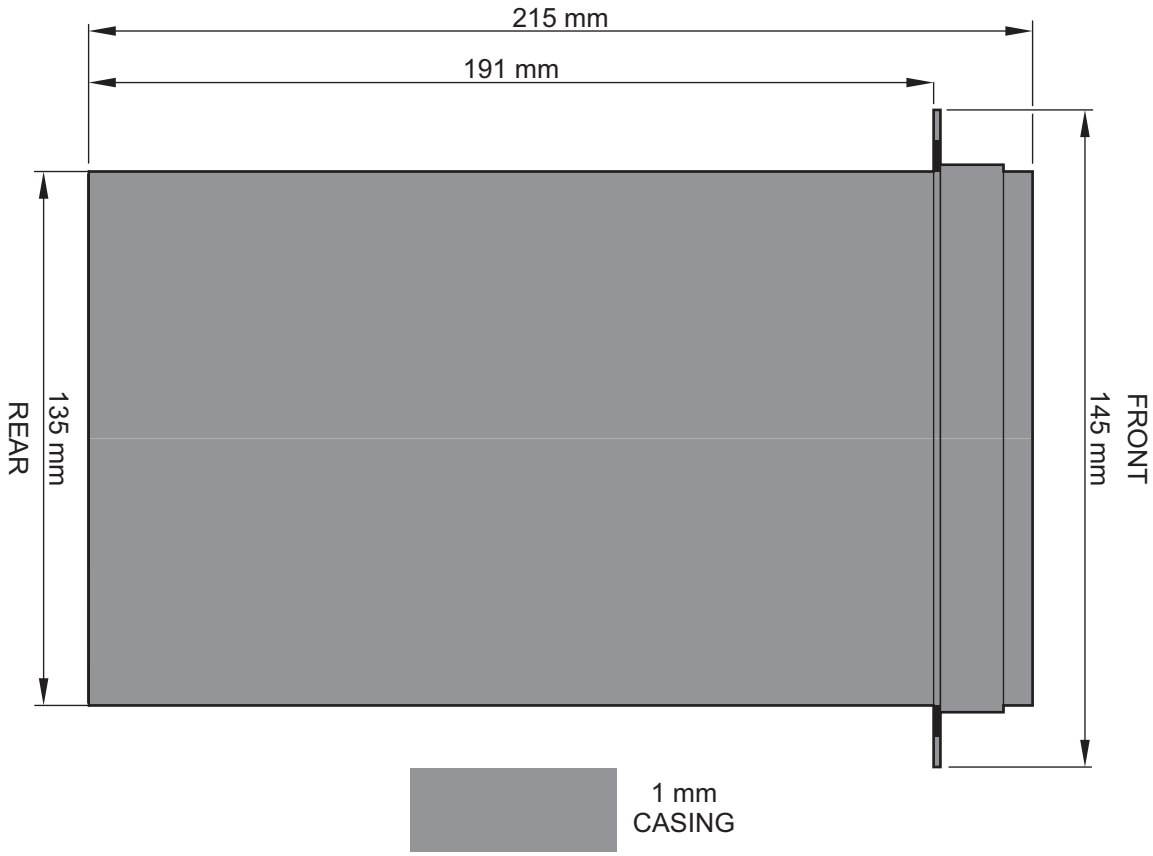


Figure 47 – Relay dimensions – bird's eye view

10.2 Relay Connections

All connections to the relay are made at the rear through Phoenix type connectors. The connections are grouped by function and numbered alphabetically (shown in Figure 48).

Each group of connections is considered in turn in the following sections with tables describing the functions and diagrams showing implementation.

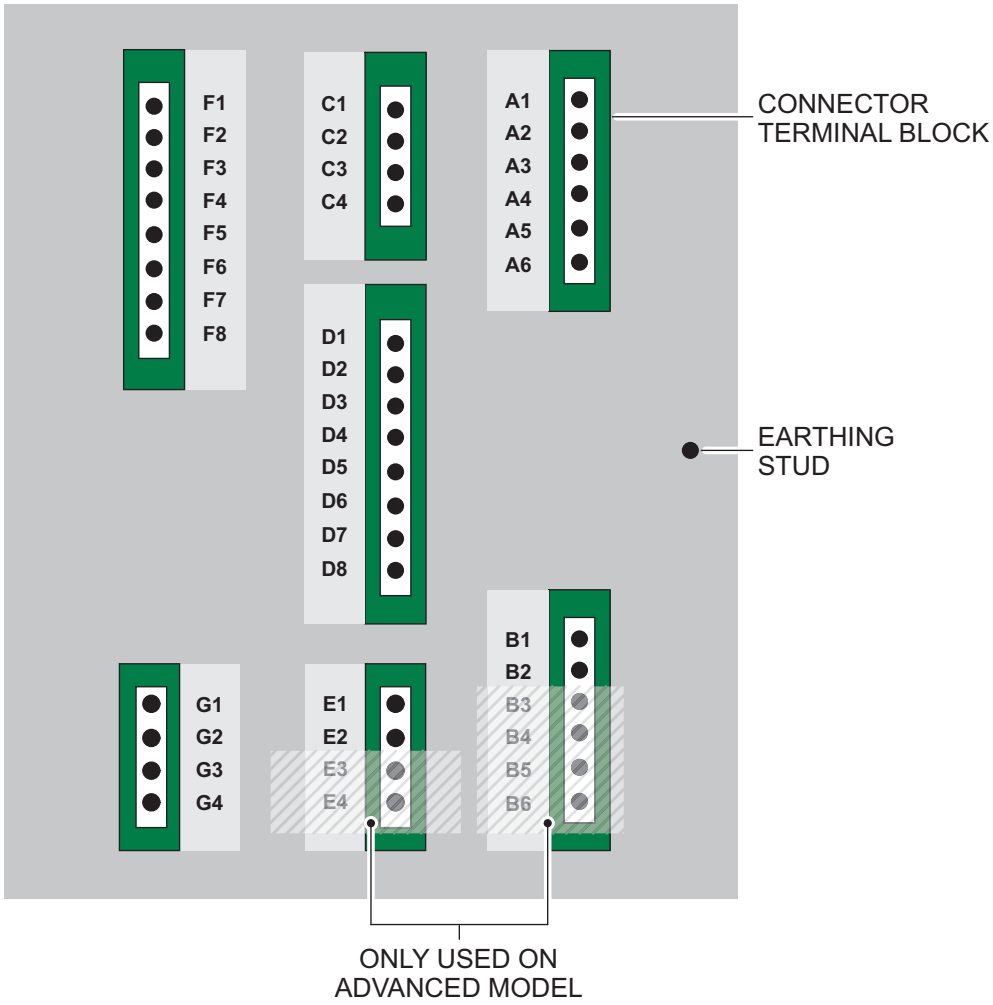


Figure 48 – Relay connections

10.2.1 Power Supply

The relay is designed with flexibility in mind. The switched-mode power supply employed has a wide voltage operating range of 80V AC to 260V AC and 90V to 140V DC. The maximum power consumption is 5W.

Table 5 – Power supply terminals

Terminal number	Description
A1	Safety Earth
A2	Safety Earth
A3	Supply Voltage (+)
A4	Supply Voltage (+) for Looping
A5	Supply Voltage (-)
A6	Supply Voltage (-) for Looping

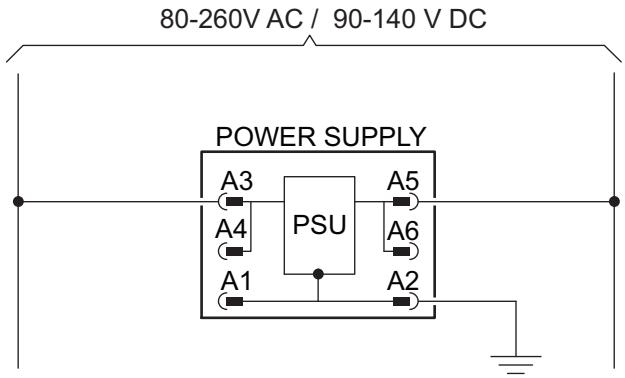


Figure 49 – Power supply connections

10.2.2 Current Measurement Inputs

Three current inputs are available for use with any phase mounted CT. Two types of current measurement are possible; transformer current (via the transformer LDC CT) and feeder current (via breaker CT). In traditional AVC applications only the former are used (basic relay model). For advanced AVC applications, such as schemes with embedded generation, both types are used (advanced relay model).

Table 6 – CT terminals

Terminal number	Description
B1	CT1 S1
B2	CT1 S2
B3	CT2 S1
B4	CT2 S2
B5	CT3 S1
B6	CT3 S2

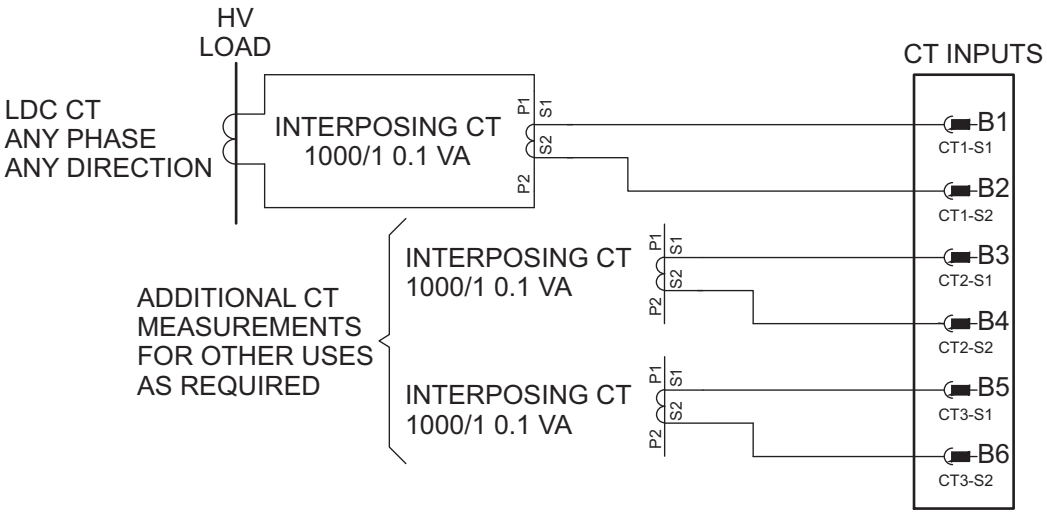


Figure 50 – CT connections

Normally, feeder current measurements are only possible using protection CT's. In order that the protection scheme is not compromised, low burden interposer CT's are used to interface with the relay. The use of such interposers gives the following additional advantages:

- Safety – no risk of high voltages for open-circuit (clamped at around 11 V)
- Flexibility – accuracy can be 'tuned' by additional interposer turns

The SuperTAPP n+ relay is designed for use with a low burden interposer CT for all current measurements. The interposers are supplied with the relay, and are described in more detail in the following section.

10.2.3 Interposer CT

The interposer CT designed for use with the SuperTAPP n+ voltage control system provides a high level of electrical isolation between the source current circuitry. It imposes virtually no burden upon the measurement current transformer (< 0.05 VA).

Figure 51 and Figure 52 give an external view of the interposer unit. The device is mounted in a DIN rail type enclosure with screwed terminal output connections available from either side of the unit.

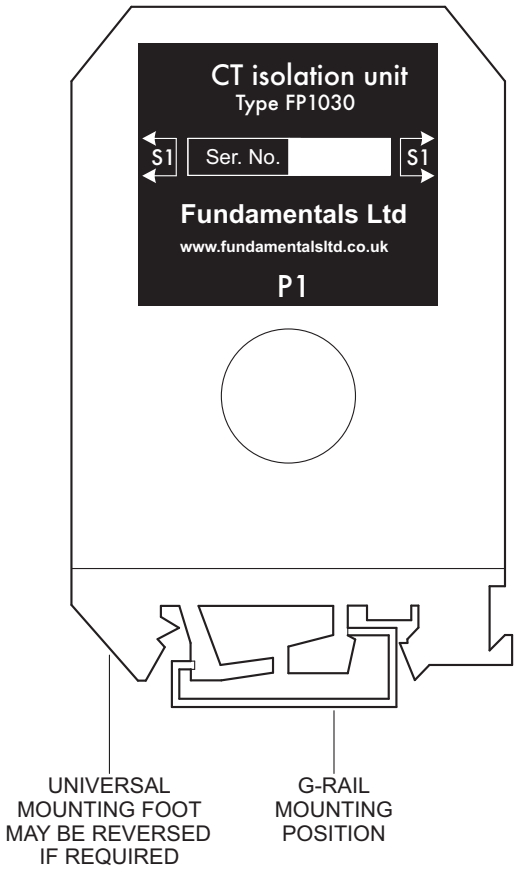


Figure 51 – Interposer CT

The primary conductor (S1 from primary CT) is passed through a central hole in the casing as shown in figures 51 and 52. The enclosure is mounted on the reversible universal foot that will allow fixing onto either a G-rail or DIN-rail mounting arrangement.

The interposer CT should be mounted in a convenient position such that the distance between the unit and the relay is at a practical minimum. If there is substantial distance between the unit and the device, a twisted pair cable should be used. This may be the case where a protection CT is utilised. In this instance the interpose CT should be mounted as close as possible to the primary CT secondary wiring and in any event in the same panel. The specification for the interposer CT is shown in table 7.

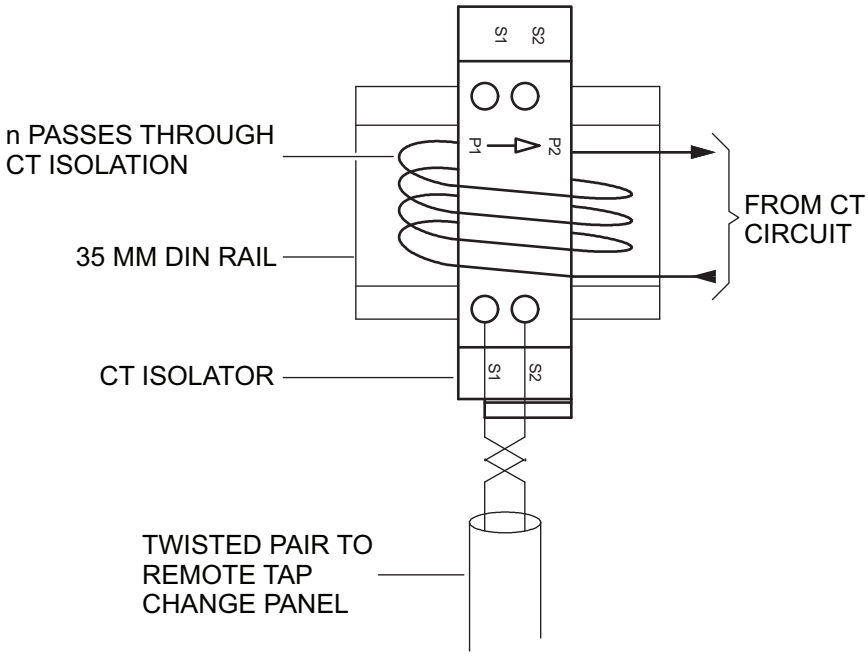


Figure 52 – Interposer CT connections

Table 7 – Interposer CT specification

Parameter	Specified value
Ratio	10A : 0.01 A
Maximum primary current	10 A
Burden	0.03 VA
Isolation	> 3 kV
Material	UV 94-V-0 polyamide 66/6

The maximum current that the device can measure with accuracy is 10 amps. Depending on the use of the interpose unit, turns can be added to the primary side in order to increase the sensitivity of the output. It is recommended that the number of turns should give ‘5 Amp turns’ at rated current as shown in Table 8 and Figure 52.

Table 8 – Interposer CT turns

CT secondary rating	Interposer turns required
5 A	1
1 A	5
0.5 A	10

In situations where the loading on the CT is low compared to the rating, accuracy can be compromised. The number of turns on the interposer can be increased to improve the accuracy, but care is required and in any case it is not recommended to increase the number of turns above 5 Amp-turns at the normal maximum loading level. The maximum non-fault overload level should be less than 10 Amp-turns.

For example, a feeder breaker CT (ratio 1000:5) would normally have a single interposer turn. If the maximum loading of the feeder is 200 A, the number of turns could be increase to 5 to give more accuracy.

The settings for each CT input need to be configured appropriately in order that the relay can convert the measurements into the correct primary values (see CT settings in section 11.3.2).

10.2.4 Tap Changer Outputs

The raise and lower outputs are used to initiate a tap change when the measured voltage is outside of the 'dead band'. Normally a raise will increase the tap position and the measured voltage, and a lower vice-versa. However, tap changers can sometimes work in the opposite direction where an increase in tap position will produce a lower voltage. The outputs should be wired such that raise produces a higher voltage. These outputs have normally open contacts and are rated 12 A continuous.

Table 9 – Tap changer output terminals

Terminal number	Description
C1	Lower Tap Pulse
C2	Common
C3	Common
C4	Raise Tap Pulse

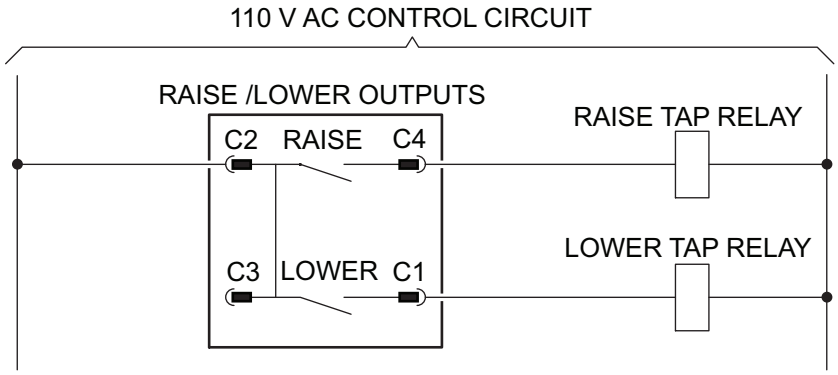


Figure 53 – Tap changer output connections

10.2.5 Status Outputs

The relay has a number of outputs used to indicate the status of the voltage control system. These are normally wired into the telecontrol/SCADA scheme for display at the control room. The output contacts are rated 12 A continuous.

Table 10 – Status output terminals

Terminal number	Description
D1	Relay Healthy Common
D2	Relay Healthy
D3	Relay Fail
D4	AVC Alarm Common
D5	AVC Alarm
D6	Control Mode (Non-Auto)
D7	Control Mode Common
D8	Control Mode (Automatic)

The Relay Healthy output is used to indicate the health status of the relay with an associated changeover contact for operational indication. The Relay Healthy contact will be closed when the relay is healthy. The Relay Fail contact will be closed when the relay is either powered down or has problems associated with hardware (in either case the relay is not operational and cannot control voltage).

The AVC Alarm output is operated by a normally open contact and used to indicate that the relay has detected an operational problem. Error conditions are described in more detail in section 7.

The Control Mode output is used to indicate if the relay is in automatic or non-auto mode of control and is operated by a changeover contact.

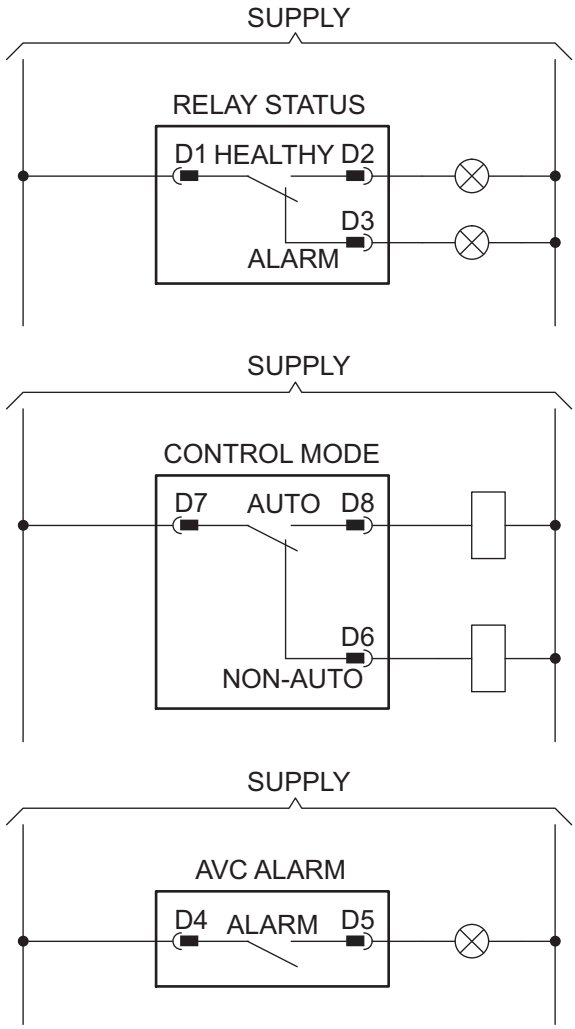


Figure 54 – Status output connections

10.2.6 Voltage Measurement Inputs

Two nominal 110V AC inputs for voltage measurements are provided rated for up to 150 V AC. The burden imposed on the VT by the relay is less than 1VA. In most schemes only a single voltage input will be used (basic relay model).

The second input is used on the advanced relay model for applications involving double-secondary winding transformers where voltage averaging and load summation is required. It will also be used for applications where a 'back-up' phase reference is required for feeder current measurements. These applications are described in more detail in section 9.

Table 11 – VT input terminals

Terminal number	Description

E1	VT1 (phase 1)
E2	VT1 (phase 2)
E3	VT2 (phase 1)
E4	VT2 (phase 2)

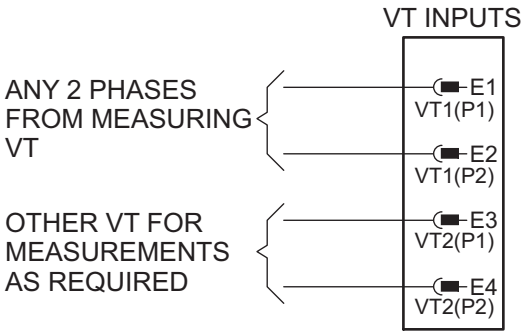


Figure 55 – VT input connections

The settings for each VT input (such as VT ratio and VT phase) need to be configured appropriately in order that the relay can convert measurements into the correct primary values (see settings in section 11.3.2).

10.2.7 Status Inputs

The relay has a number of status inputs available for use to modify the operating parameters of the voltage control system. The inputs are wired into the telecontrol / SCADA scheme and have an operating range of 20 V to 250 V AC / DC.

Table 12 – Status input terminals

Terminal number	Description	
F1	Voltage Adjustment 1	
F2	Voltage Adjustment 2	
F3	Voltage Adjustment 3	
	'Auto Select Mode' Setting *	
	Level Detect	Edge Detect
F4	Remote/Local	Non-Auto
F5	Auto /Non-Auto	Auto
F6	Alternative Settings	
F7	Common	
F8	Common	

* found in the 'Relay Config' settings menu

Inputs F1, F2 and F3 are used for voltage target adjustments, normally for voltage reduction when load shedding is taking place. When energised, the inputs result in a change to the relay target voltage level. See section 8.3 for detail of how the voltage adjustments operate (the inputs can be configured to respond to permanent or fleeting signals).

The function of status inputs F4 and F5 is dependent on the 'Auto Select Mode' setting as shown in Table 12. Where the setting is set to 'level detect' (permanent signal), F4 functions as Remote (signal on) / Local (signal off) and F5 as Auto (signal on) / Non-Auto (signal off). Where the setting is set to 'edge detect' (fleeting signal), F4 functions as Non-Auto, F5 as Auto (no facility for Remote/Local).

Input F6 is used to switch the relay to use a different set of key settings as defined in the 'Alternative Settings' menu and shown in Table 13. These settings are used while the status input is energised (permanent signal).

Table 13 – Alternative settings

Setting Type	Setting	Range	Default setting
Alternative Settings	Target voltage	90 % - 110 % step 0.1 %	100 %
	Bandwidth	0.5 % - 5 % step 0.1 %	1.5 %
	LDC	0 % - 20 % step 0.1%	2.5%
	Reverse LDC	On/Off	Off
	Group ID	1 – 6	1
	Load Ratio *	0 – 200 %	0 %
	Generator Bias *	0 – 10% step 0.1 %	0 %
	Firm Capacity	50 – 10000 step 1	1575 A
	Power Factor	0.5 lag – 1.0 – 0.9 lead	0.96 lag
	Reverse Power Factor*	Disabled, -0.5 lag - -0.5 lead step 0.01	Disabled
	Reverse LDC Level*	Disabled, -0.1% - -20% step 0.1%	Disabled
	Max Reverse Load*	Disabled, -50 A - - 10000 A step 1	Disabled
	Network Circ. Factor	10 – 100 %, step 1%	10%
	Feeder Measurements *	Use or Ignore	Ignore

* Not shown for a 'basic' model

Alternative settings are intended to offer flexibility for abnormal operating conditions such as:

- Topology changes – where transformers which are normally operated in parallel are temporarily switched apart by opening of a bus section for example. In this situation it will be necessary to alter the group ID of at least one unit (see section 4.6.3 for a description of this).
- Network changes – where the configuration of outgoing feeders is changed and require different settings (e.g. LDC settings).

The alternative settings may be particularly useful for the more 'advanced' applications where extra CT and VT measurements are in use and where 'safe AVC' can be applied in the event of abnormal conditions.

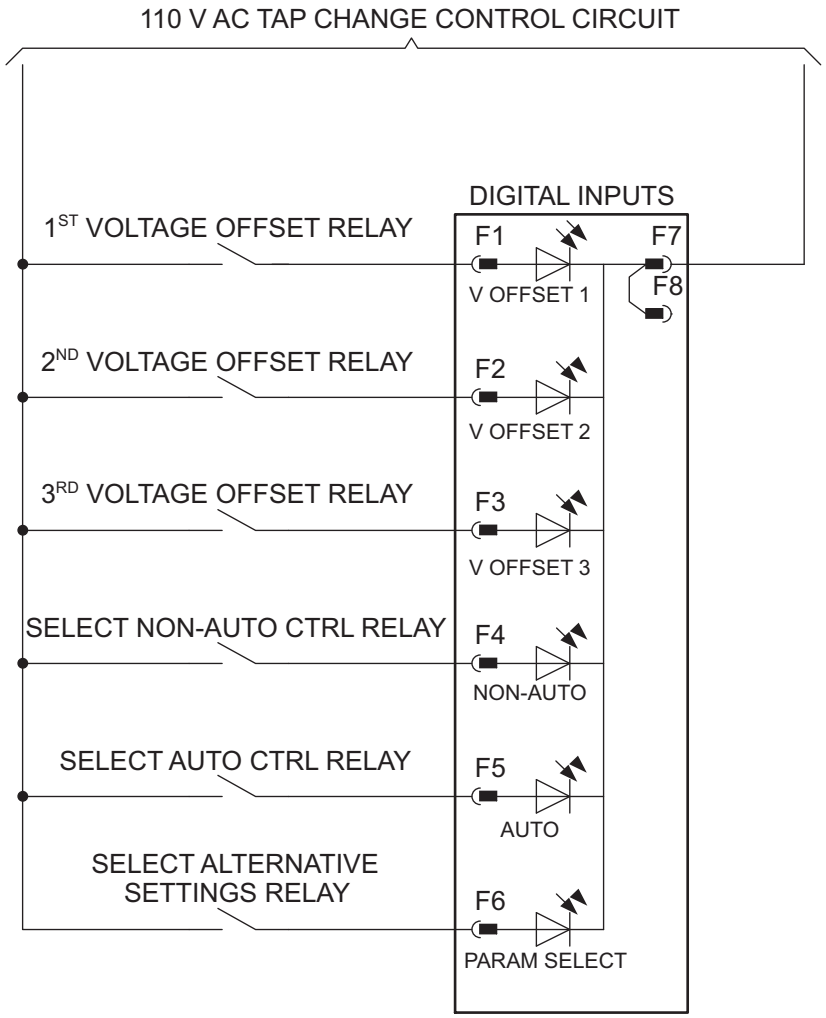


Figure 56 – Status input connections

10.2.8 CAN Bus Communications

The CAN Bus is used for communications between SuperTAPP n+ relays to allow distribution of status and measurement information. For single transformer applications it is not used. For multiple transformer applications it allows the determination of summed measurements and calculation of values which are important for AVC functions.

Each relay is connected by screened twisted pair cable in a daisy chain configuration. Relays at each end of the chain need to have a link in place between the ‘CAN Low’ (G2) terminal and the ‘CAN Termination’ terminal (G4). Correct CAN bus connections for two and three relay applications are shown in Figure 57.

Table 14 – CAN terminals

Terminal number	Description
G1	CAN Ground*
G2	CAN Low
G3	CAN High
G4	CAN Termination

* connection to ground must only be on one of the paralleled units – see Figure 57.

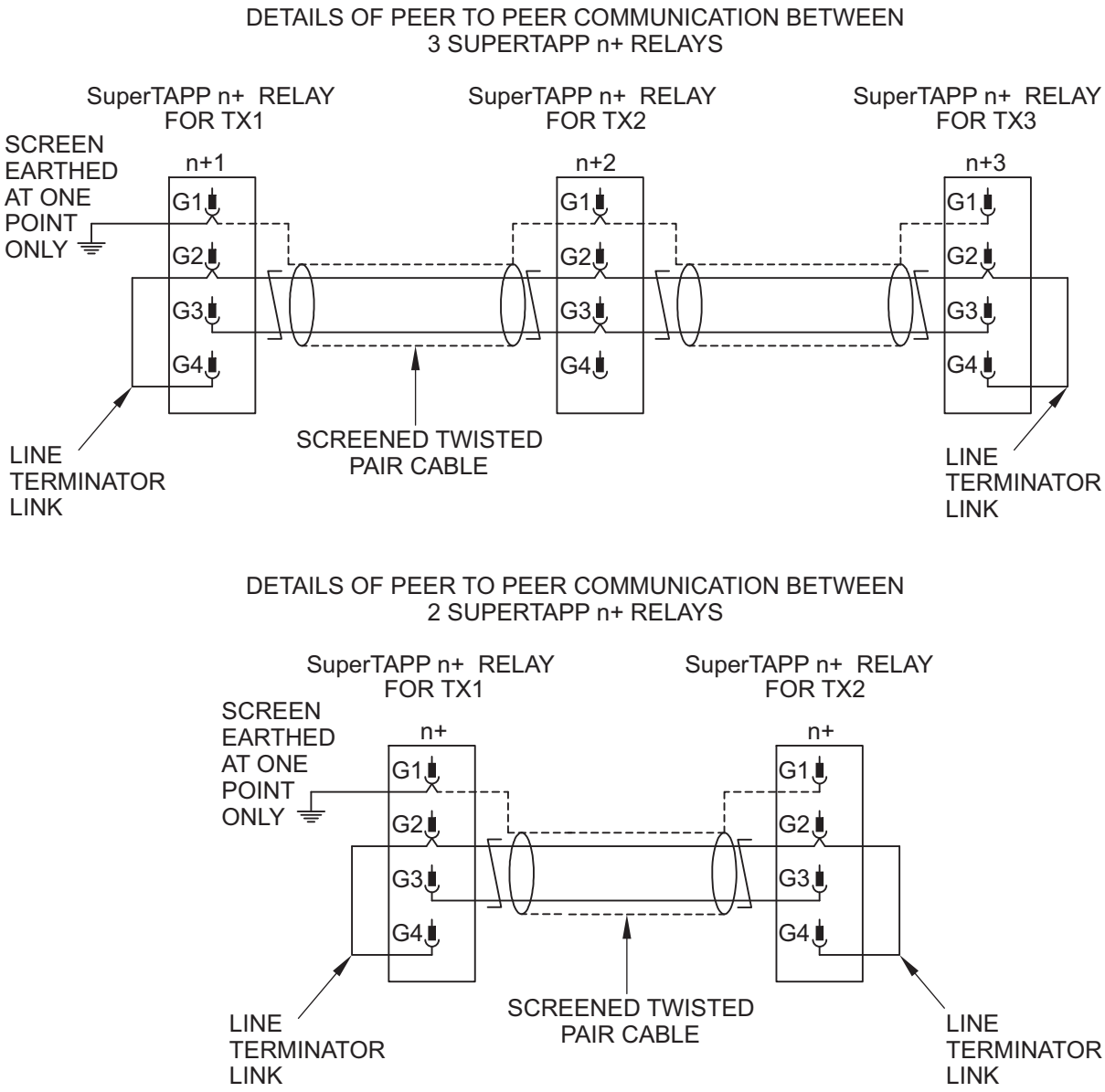


Figure 57 – CAN bus connections

The CAN communications system can accommodate a maximum of six voltage control relays, but can also accommodate an additional six Data Acquisition Modules (DAM's) where extra feeder current measurements are required for advanced applications (see section 9). The DAM is based on SuperTAPP n+ hardware, with the same form factor but different inputs and outputs. Please refer to the DAM technical literature for more information.

Instrumentation is available to show the number of units communicating on the CAN bus with corresponding groupings to check correct configuration. Figure 58 shows an example screen shot of CAN instrumentation. See the instruments section 11.3.1 for more details.

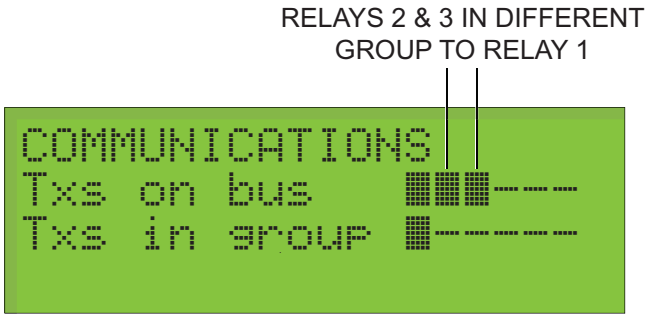


Figure 58 – CAN bus instruments

The CAN bus is very important for correct operation of the SuperTAPP n+ system and should therefore be set up correctly. CAN bus faults and errors with suggested fixes are shown in Table 15.

Table 15 – CAN bus errors

Relay display message	Remedy
Communications error	Check diagnostic instruments and CAN bus wiring
Comms ID clash	Check transformer ID setting
Comms data missing	Check diagnostic instruments and for errors or power fail on other relays
DAM error	Check for errors on connected DAM units

10.3 Accuracy

Table 16 – Relay accuracy

Quantity	Range	Tolerance
Operating voltage range (RMS) 47Hz – 63Hz	80% - 120% of target	±0.2%
Bandwidth	±0.5% - ±5%	±0.1%
No voltage detection	<25% of target	±1%
Power Factor	1 – 0.5 lead/lag 0.5 – 0 lead/lag	±1%
Current (RMS)	5% - 20% x CT primary 20% - 200% x CT primary	±2% of nominal

LDC	0% - 10%	±0.2%
Initial time delay	Through range	±1 sec
Inter-tap delay	Through range	±1 sec
Over-current blocking	50% - 200%	±5%

10.4 Type Tests

The SuperTAPP n+ has been tested in accordance with the Energy Networks Association (ENA) Technical Specification EATS 48-5 Issue 2 2000, 'Environmental Test Requirements for Protection Relays and Systems'. This test specification was produced by the Electricity Association Protection Panel in consultation with manufacturers of protection equipment and applies to equipment intended for use within the UK electricity supply industry.

The specification recommends atmospheric, mechanical, electrical and EMC tests to be performed according to specified standards. Details and results of these tests are presented in Appendix D.

11 HMI

11.1 Relay Fascia

The SuperTAPP n+ has been designed with the user in mind, with a simple front display and meaningful fascia indications. A single control knob allows navigation through the menu system and application of settings. Comprehensive instruments are included to provide measurement, status and diagnostic information, allowing the user to fully observe and understand relay operation. The relay fascia is shown in Figure 59.

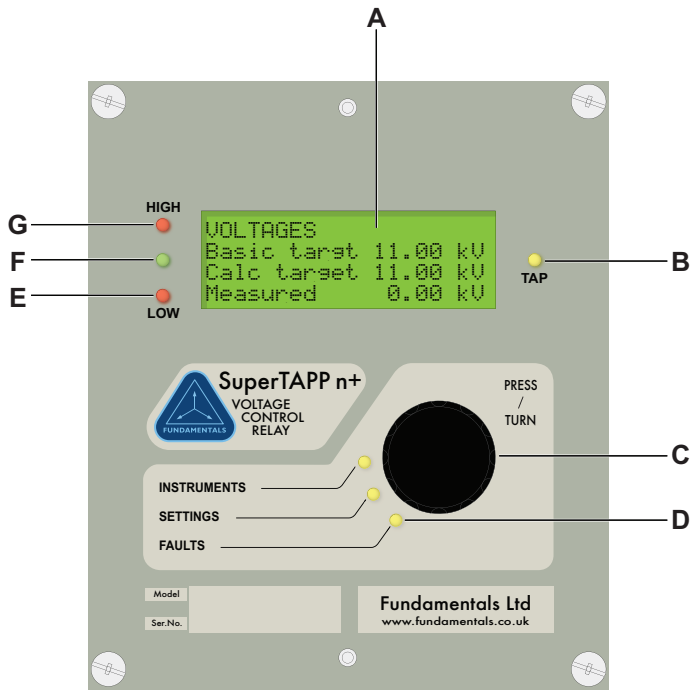


Figure 59 – Relay fascia

A. Four line LCD for display of measurement and status information

B. Tap in progress indication LED

C. Control knob for menu system navigation and settings changes

D. LED indications for menu system navigation

E. Voltage low (solid) / Voltage very low (flashing)

F. Normal voltage (solid) / Overload (flashing)

G. Voltage high (solid) / Voltage very high (Flashing)

The relay has LED indications on the fascia and a four-line LCD with backlighting. The backlighting is activated by a push of the control knob and deactivated after 5 minutes of inactivity.

11.2 Display Messages

Table 17 – Display messages

Relay Message	Description
Hardware error	There is a problem with the relay hardware. Please contact Fundamentals for support.
Measurement error	There is a problem with a voltage or current measurement. Please contact Fundamentals for support.
Uncalibrated input	One of the voltage or current inputs is not calibrated. Please contact Fundamentals for support.
Overloaded input	One of the voltage or current inputs is overloaded. The maximum measurements are 150 Volts or 10 Amp-turns.
Mismatched VT inputs	The signals on the two voltage inputs differ by more than 10% in magnitude or 20°in angle. Please check your VT and CT settings.
Comms ID clash	Two relays have been set to the same Transformer ID. They are unable to exchange data.
Communications error	Data is unexpectedly no longer being received from another relay. Please check your CAN wiring.
DAM error	A connected Data Acquisition Module has experienced a fault.
Comms data missing	A connected relay has been powered off or is unable to make measurements.
Over current	The measured transformer current is greater than the set overcurrent level. Tap changes are inhibited.
Zero voltage	The measured transformer voltage is less than 25% of target. Automatic control is inhibited.
Under voltage	The measured transformer voltage is less than 80% of target. Automatic control is inhibited.
Voltage out of band	The measured transformer voltage is outside the set bandwidth and automatic control is disabled.
Auto ctrl disabled	Automatic voltage control is disabled.
Time to tap	The relay is timing down to a tap change.
Raising voltage	The relay is issuing a ‘tap up’ command.
Lowering voltage	The relay is issuing a ‘tap down’ command.
Preparing switch out	The relay is preparing the transformer to be switched out.
Ready to switch out	The transformer is ready to be switched out.

11.3 Menu System

Various screens are displayed on the LCD via the menu system. Navigation through the menu system is provided using the control knob (push and turn) on the relay fascia. The default screen can be accessed at any time by pressing and holding the control knob in for more than 1 second (this will cancel any unsaved settings changes). The relay will automatically return to the default screen after 10 minutes of inactivity.

The display menu system is accessed from the default screen and has three top-level items, each with a corresponding LED on the relay fascia:

- Instruments
- Settings
- Faults

With the relay lid in place, the user is limited to push button control (no turn) and can only view the summary instruments screens. With the lid off, the user can turn and push the button and is free to navigate throughout the menu system. Figure 60 shows the structure of the menu system (each menu item shown contains sub-menus). The contents of each menu item are described in detail in the following sections.

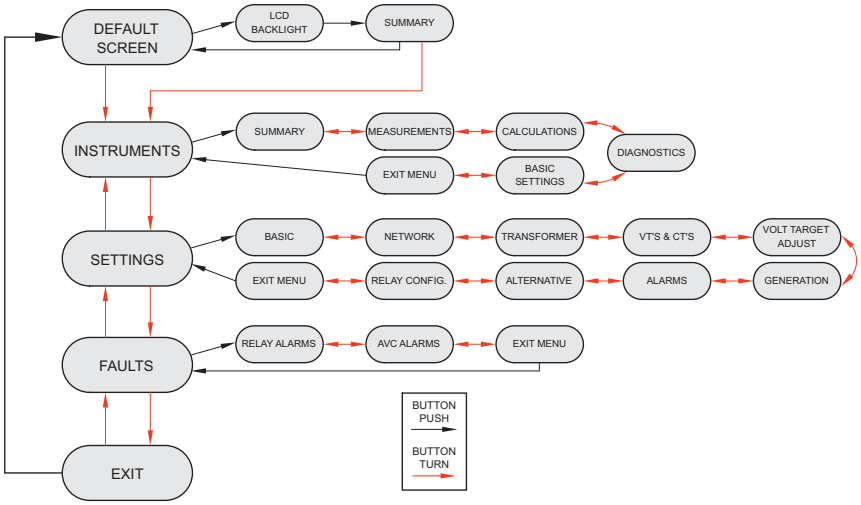


Figure 60 – Menu system

11.3.1 Instruments

The instruments menu allows the user to view system data that give measured and calculated values. The menu is shown in Figure 61. The displayed data is described in Table 18.

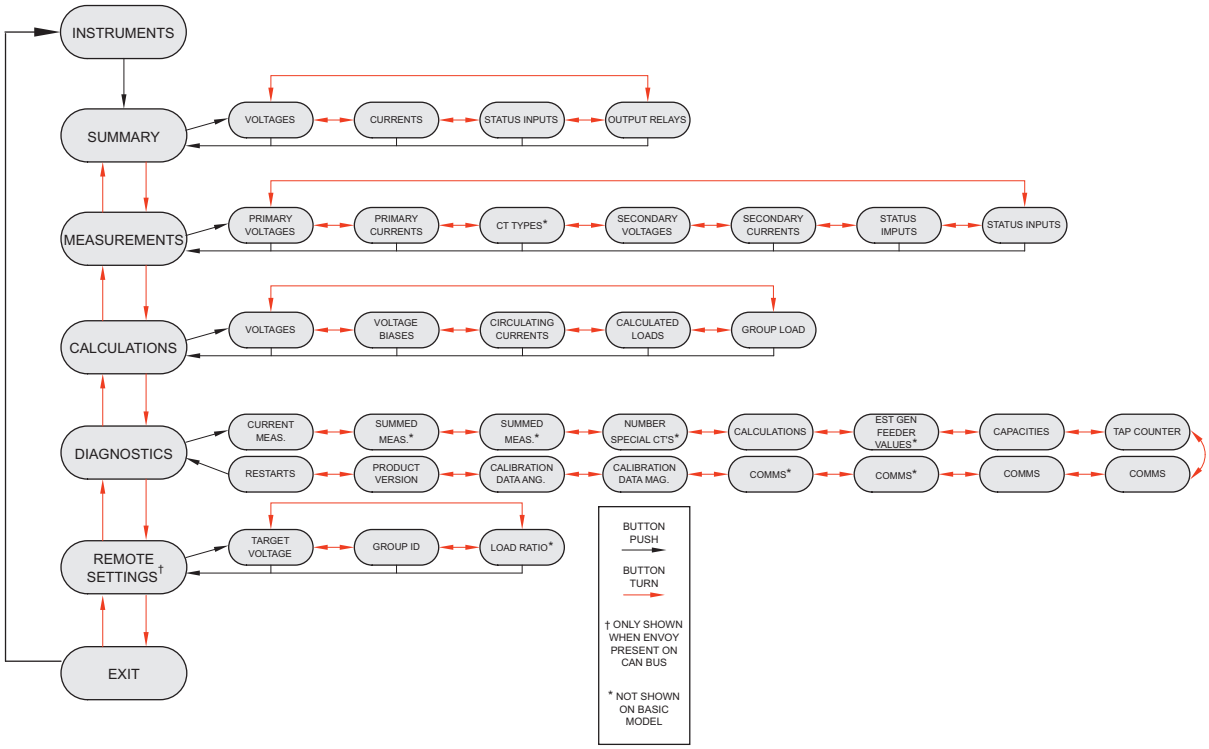


Figure 61 – Instruments structure

Table 18 – Instruments details

Instrument	Name	Display Data	Comments
Summary	VOLTAGES	Basic target (kV)	
		Calc. target (kV)	
		Measured (kV)	
	CURRENTS	Group load (A /pf)	
		Generator (A / pf) *	
		Site circ. (A)	
	STATUS INPUTS	Remote (On) / Local (Off) OR Auto (On/Off)*	- = Off ▉ = On
		Auto (On) / Non-auto (Off) OR Non-auto (On/Off)*	
		Alternative settings (On/Off)	
		V targ1 / V inc (On/Off)	
		V targ2 / V dec (On/Off)	
		V targ3 / V reset (On/Off)	
	OUTPUT RELAYS	Raise (On/Off)	- = Off ▉ = On
		Lower (On/Off)	
		Auto (On/Off)	
		Healthy (On/Off)	
		AVC alarm(On/Off)	

Instrument	Name	Display Data	Comments
Measurements	PRIMARY VOLTAGES	V1 (kV)	
		V2 (kV) *†	
		Phase reference (V1 / V2) *†	
	PRIMARY CURRENTS	C1 (A / pf)	
		C2 (A / pf) *†	
		C3 (A / pf) *†	
	CT TYPES *	C1 Type *	
		C2 Type *†	
		C3 Type *†	
	SECONDARY VOLTAGES	V1 (V / ˚)	
		V2 (V / ˚) *†	
		Phase reference *†	
	SECONDARY CURRENTS	C1 (mA / ˚)	
		C2 (mA / ˚) *†	
		C3 (mA / ˚) *†	
	STATUS INPUTS	Remote (On) / Local (Off) OR Auto (On/Off)◊	− = Off ▉ = On
		Auto (On) / Non-auto (Off) OR Non-auto (On/Off) ◊	
		Alternative settings (On/Off)	
		V targ1 / V inc (On/Off)	
		V targ2 / V dec (On/Off)	
		V targ3 / V reset (On/Off)	
	OUTPUT RELAYS	Raise (On/Off)	− = Off ▉ = On
		Lower (On/Off)	
		Auto (On/Off)	
		Healthy (On/Off)	
		AVC alarm (On/Off)	
Calculations	VOLTAGES	Basic target (%)	
		Calc. target(%)	
		Measured (%)	
	VOLTAGE BIASES	Circ. current (%)	
		LDC (%)	
		Generator (%) *	
	CIRCULATING CURRENTS	Site (A)	
		Network (A)	
	CALCULATED LOADS	Group (A/pf)	
		Generator (A/pf) *	
	GROUP LOAD	MVA	
		MW	

Instrument	Name	Display Data	Comments
		Mvar	
Diagnostic Instruments	CURRENT MEASUREMENTS	Transformer (A/pf)	
		Summed transformers (A/pf)	
	SUMMED MEASUREMENTS *	Generator feeders (A/pf) *	
		Generators (A/pf) *	
	SUMMED MEASUREMENTS *	Excluded loads (A/pf) *	
		Corrected loads (A/pf) *	
		Included loads (A/pf) *	
	NUMBER SPECIAL CT'S *	Generator feeders *	
		Generators *	
		Extra transformers *	
		Excluded loads *	
		Included loads *	
		Corrected loads *	
	CALCULATIONS *	Non-measured load (A/pf) *	
	ESTIMATED GENERATOR FEEDER VALUES *	Load (A/pf) *	
		Generation (A/pf) *	
	CAPACITIES	Generation (A) *	
		Summed transformer ratings (A)	
	TAP COUNTER	No. of taps	
	COMMUNICATIONS	Transformers on bus	
		Transformers in group	
	COMMUNICATIONS	Transformers missing	
		Transformers off	
		Transformers in error	
	COMMUNICATIONS *	DAM's on bus *	
		DAM's in group *	
	COMMUNICATIONS *	DAM's missing *	
		DAM's off *	
		DAM's in error *	
	CALIBRATION DATA MAGNITUDE	V1	
		V2 *	
		C1	
		C2 *	
		C3 *	
	CALIBRATION DATA ANGLE	V1	
		V2 *	
		C1	
		C2 *	

Instrument	Name	Display Data	Comments
		C3 *	
	PRODUCT VERSION	Product ID	
		Article number	
		Compile time	
	RESTARTS	Number of restarts	
		Uptime	
		Reason	
Remote Settings	VIEW REMOTE SETTINGS	Target voltage (%)	
		Group ID	
		Load ratio (%)	

* Not shown for a basic model

† Not shown if inputs are set to 'Unused' on an advanced model

◊ Dependent on the 'Auto select mode' setting

11.3.2 Settings

The settings menu allows the user to view and amend relay settings. The full settings menu is shown in Figure 63. Settings data with default values and ranges is shown in Table 19.

Edit Mode

Edit mode is selected by pressing the control knob when the setting to be amended is displayed on the screen. In this mode the user can turn the control knob to change the setting. Some settings with wide ranges have coarse and fine adjustments to reduce the number of control knob turns required. Other settings have a fixed number of options to choose from.

When the desired setting value/option is attained, the control knob is pushed to store the new value in memory and exit edit mode. The user can move to other settings within the setting menu for edit, or proceed to exit the setting menu, at which point the user has two options:

- Save change and exit
- Reject changes and exit

An example of the setting changes screen is shown in Figure 62.

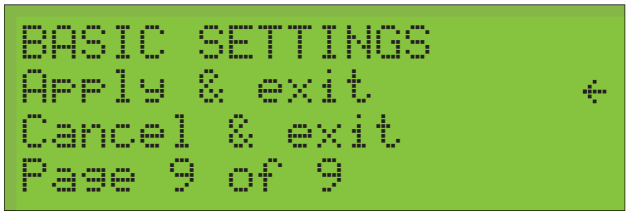


Figure 62 – Settings change

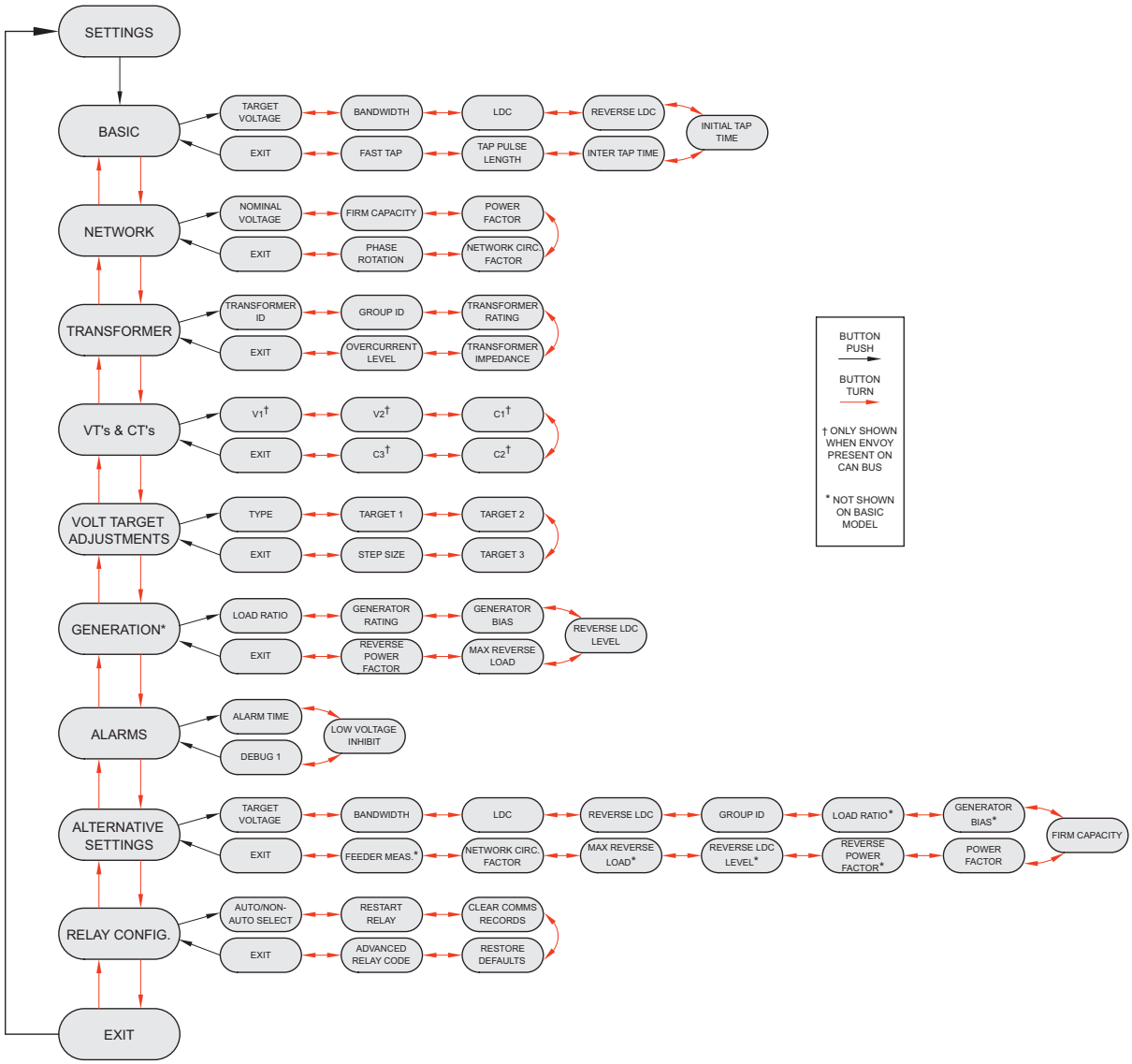


Figure 63 – Settings structure

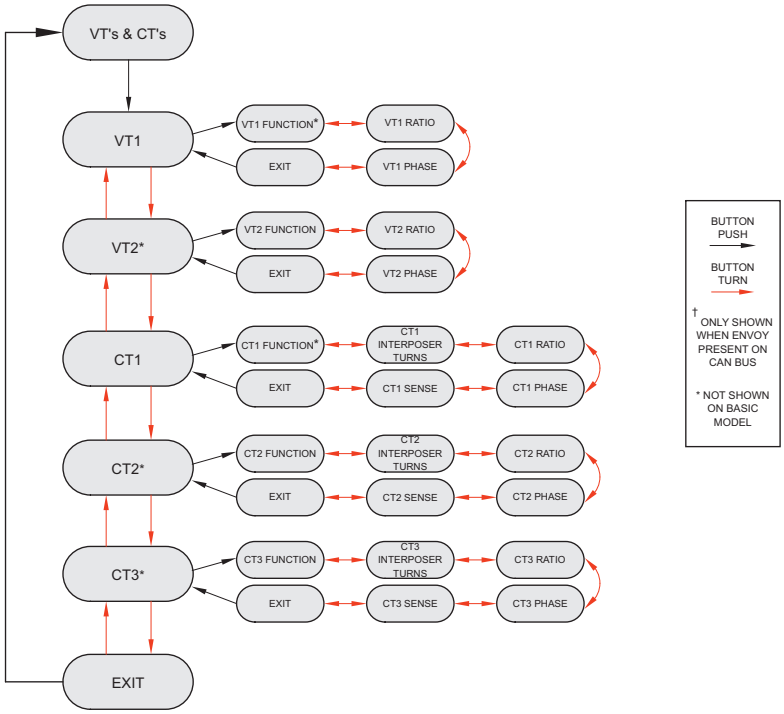


Figure 64 – VTs and CTs settings

Table 19 – Settings details

Setting Type	Setting	Range	Default setting
BASIC	Target voltage	90 % - 110 % step 0.1 %	100 %
	Bandwidth	0.5 % - 5 % step 0.1 %	1.5 %
	LDC	0 % - 20 % step 0.1%	2.5%
	Reverse LDC	Disabled / Enabled	Disabled
	Initial tap time	10 – 120 sec step 1	120 sec
	Inter-tap time	5 – 120 sec step 1	15 sec
	Tap pulse length	1 sec to 5 sec step 1 sec.	2 sec
	Fast tap	Disabled, Down, Up/down	Down
NETWORK	Nominal voltage	3 – 160 kV step 0.1	11 kV
	Firm capacity	50 – 10000 A step 1	1575 A
	Power factor	0.5 lag – 1.0 – 0.9 lead step 0.01	0.96 lag
	Network circ. factor	10 – 100 %, step 1%	10%
	Phase rotation	‘ABC’ or ‘CBA’	‘ABC’
TRANSFORMER	Transformer ID	1-6	1
	Group ID	1-6	1
	Transformer rating	50 -5000 step 1	1575 A
	Transformer impedance	5 % -50 % step 0.1 %	30 %
	Overcurrent level	50 – 200 % step 1%	130 %

Setting Type		Setting	Range	Default setting
VT's & CT's	V1	V1 function*	Voltage Control, Voltage Reference, Unused	Voltage Control
		V1 ratio	10 – 2000 step 0.1	100
		V1 phase	A-B, B-C, C-A, A-E, B-E, C-E	B-C
	V2 *	V2 function *	Voltage Control, Voltage Reference, Unused	Unused
		V2 ratio *	10 – 2000 step 0.1	100
		V2 phase *	A-B, B-C, C-A, A-E, B-E, C-E	B-C
	C1	C1 function*	Unused, Transformer, Generator Feeder, Generator, Corrected, Excluded, Monitor, Interconnector, Included, Extra Transformer	Transformer
		C1 interposer turns	1-10	5
		C1 ratio	10 – 6000 step 1	1600
		C1 phase	A, B, C	A
		C1 sense	Normal, Reversed	Normal
	CT2 *	C2 function *	Unused, Transformer, Generator Feeder, Generator, Corrected, Excluded, Monitor, Summed Transformer, Included, Extra Transformer	Unused
		C2 interposer turns *	1-10	5
		C2 ratio *	10 – 6000 step 1	1600
		C2 phase *	A, B, C	A
		C2 sense *	Normal, Reversed	Normal
	CT3 *	C3 function *	Unused, Transformer, Generator Feeder, Generator, Corrected, Excluded, Monitor, Summed Transformer, Included, Extra Transformer	Unused
		C3 interpose turns *	1-10	5
		C3 ratio *	10 – 6000 step 1	1600
		C3 phase *	A, B, C	A
		C3 sense *	Normal, Reversed	Normal
VOLTAGE TARGET ADJUSTMENT		Type	Fixed, Step	Fixed
		Target 1	-6 % to +6 % step 0.1 %	-3 %
		Target 2	-6 % to +6 % step 0.1 %	-6 %
		Target 3	-6 % to +6 % step 0.1 %	3 %
		Step size	0.5 % to 3 % step 0.1 %	1 %
GENERATION *		Load ratio *	0 – 200 % step 1%	0 %
		Generator rating *	0 – 5000 A step 1	0 A
		Generator Bias *	0 – 10% step 0.1 %	0 %
		Reverse LDC level*	Disabled, -0.1% - -20% step 0.1%	Disabled

Setting Type	Setting	Range	Default setting
	Max reverse load*	Disabled, -50 A - - 10000 A step 1	Disabled
	Reverse power factor*	Disabled, -0.5 lag - -0.5 lead step 0.01	Disabled
ALARMS	Alarm time	180 – 900 sec step 5	300 sec
	Low voltage inhibit	80% - 0% step 5%	80%
ALTERNATIVE SETTINGS	Target voltage	90 % - 110 % step 0.1 %	100 %
	Bandwidth	0.5 % - 5 % step 0.1 %	1.5 %
	LDC	0 % - 20 % step 0.1%	2.5%
	Reverse LDC	Disabled, -0.1% - -20% step 0.1%	Disabled
	Group ID	1 – 6	1
	Load ratio *	0 – 200 %	0 %
	Generator bias *	0 – 10% step 0.1 %	0 %
	Firm capacity	50 – 10000 step 1	1575 A
	Power factor	0.5 lag – 1.0 – 0.9 lead	0.96 lag
	Reverse power factor*	Disabled, -0.5 lag - -0.5 lead step 0.01	Disabled
	Reverse LDC level*	Disabled, -0.1% - -20% step 0.1%	Disabled
	Max reverse load*	Disabled, -150 A - - 10000 A step 1	Disabled
	Network circ. factor	10 – 100 %, step 1%	10%
	Feeder measurements *	Use or Ignore	Ignore
RELAY CONFIG	Auto select mode	Edge, Level	Edge
	Restart relay	No, Yes	No
	Clear comms records	No, Yes	No
	Restore defaults	No, Yes	No
	Advanced relay code	0 – 9999 step 1	0

* Not shown for a basic model

11.3.3 Faults

The faults menu lists logged relay alarms which have occurred since start-up. Healthy and AVC alarms are listed separately. Each logged alarm gives the description and time since the alarm occurred in days, hours, minutes and seconds as per the screen shots shown in Figure 65.

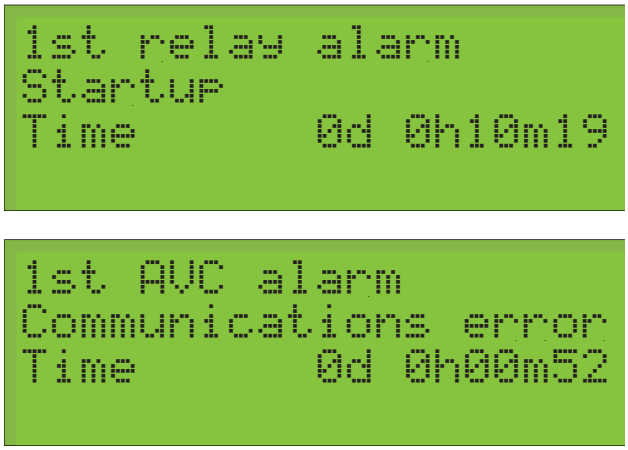


Figure 65 – Relay faults

12 Installation

12.1 Unpacking and Storage

On receipt, unpack the relay and inspect for any obvious damage. It is not normally necessary to remove the relay from its wrapping unless some damage is suspected or if it is required for immediate use. If damage has been sustained a claim should immediately be made against the carrier. The damage should also be reported to Fundamentals Ltd.

When not immediately required, return the relay to its carton and store in a clean, dry place. Equipment should be isolated from auxiliary supplies prior to commencing any work on an installation.

12.2 Recommended Mounting

The relay is normally mounted in a 19'' panel using 4mm screws with an accompanying Fundamentals RTMU monitor relay to give a complete SuperTAPP n+ voltage control system. The mounting of two systems in a cubicle allows an economic use of space for a two-transformer application as shown in Figure 66.

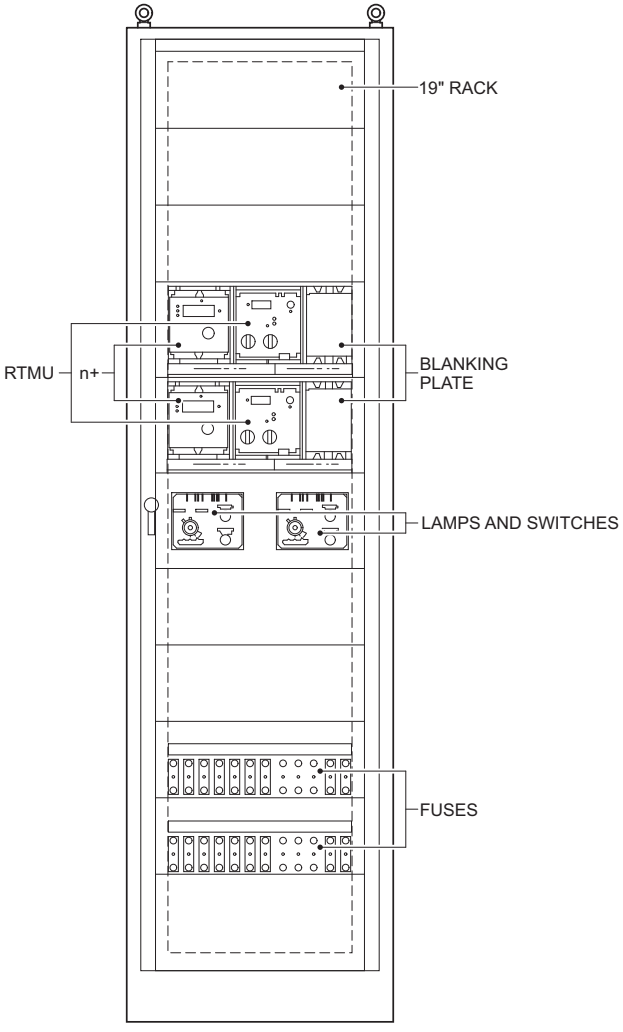


Figure 66 – Dual-relay panel

Please refer to section 10.1 for details of case size, fixing dimensions and connections of the SuperTAPP n+. Details for the RMTU relay are presented in a separate user manual.

12.3 SUPERTAPP n+ SYSTEM

The SuperTAPP n+ system comprises the SuperTAPP n+ relay and the RMTU relay. The RTMU relay is used to provide extra functions for independent monitoring and control of the tap changer:

- Tap position indication
- Voltage monitoring
- Runaway prevention
- VT fuse monitoring
- Auto/Non-auto control switches

A typical tap changer control scheme incorporating the SuperTAPP n+ system is shown in Appendix C.

13 Commissioning

13.1 Introduction

Extensive accuracy, functional, and endurance testing is carried out at the factory prior to despatch. On-site confirmation of the setting ranges and accuracy levels are not necessary. However, in order to confirm correct operation of the overall voltage control scheme there are a number of tests which should be carried out. These tests have been grouped as follows:

- General Installation
- Relay Settings
- Relay Connections
  - Analogue Inputs
  - Digital Inputs
  - Outputs
  - CAN Bus
- Tap Changer Control Modes
  - Non-auto
  - Automatic
  - Remote (SCADA communications)

Appendix B contains a commissioning sheet which can be used to record the results for each group of tests.

13.2 General Installation

Ensure that all connections are tight and in accordance with the relay wiring and diagrams and that the relay is fully inserted into the case. Note down the site name, transformer ID and relay serial number which is shown on the fascia. The software version should be recorded and can be found in the 'Product Version' screen of the Diagnostics Instruments as shown in Figure 67.

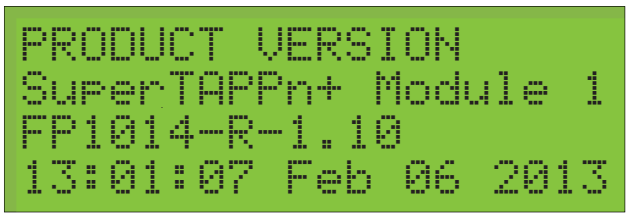


Figure 67 – Relay software version

13.3 Relay Settings

The relay settings must be configured to represent the particular application. Some settings are always used and must be configured in the relay to render it operational. The settings menus are shown in section 11.3.2. Every setting has a default which represents the most commonly experienced value. Many settings should be programmed according to the parameters of the

transformer which the relay is controlling. An example transformer nameplate is shown in Figure 68 with key parameters highlighted.

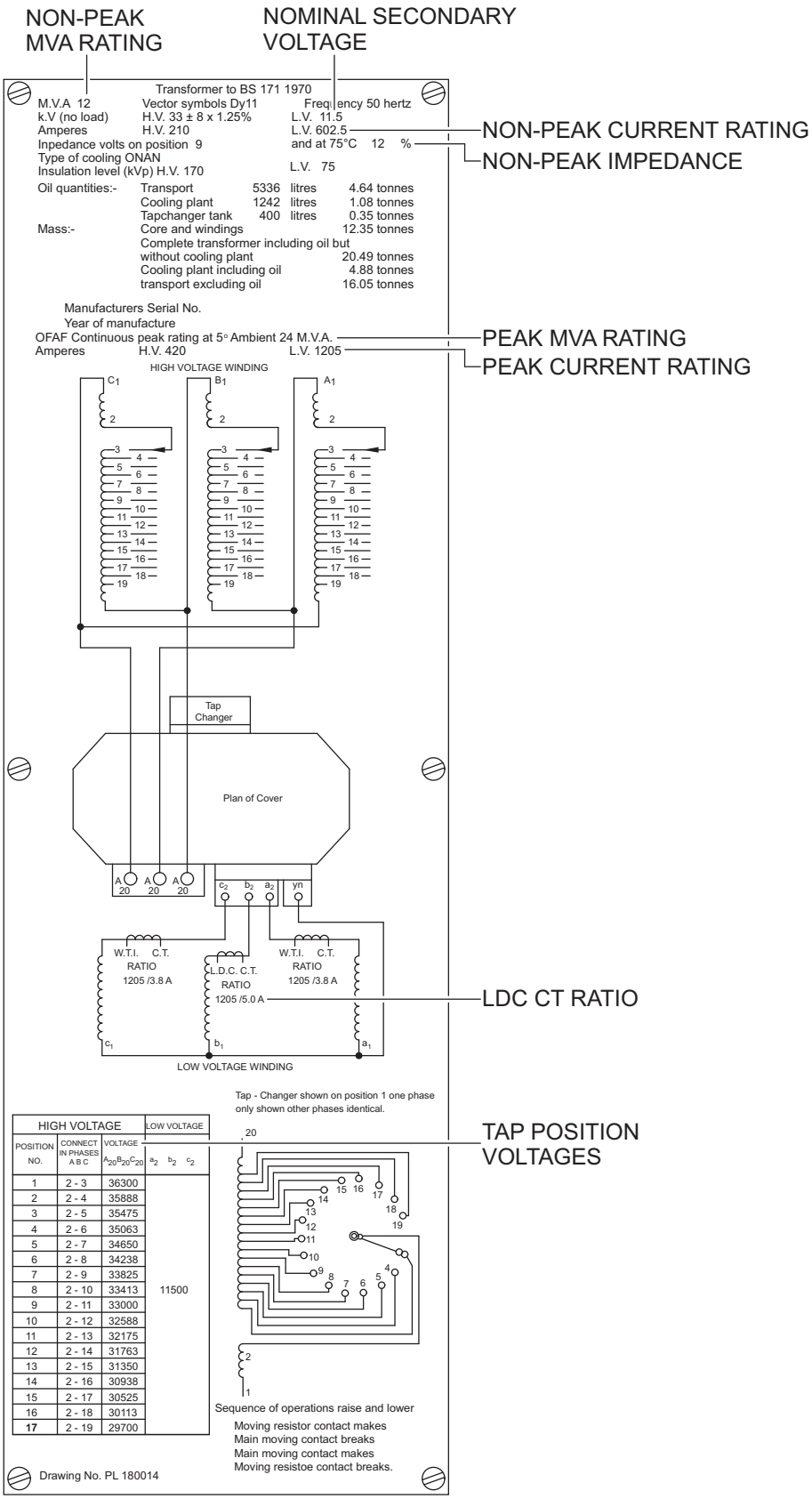
The relay settings must be configured to represent the particular application. Some settings are always used and must be configured in the relay to render it operational. The settings menus are shown in section 11.3.2. Every setting has a default which represents the most commonly experienced value. Many settings should be programmed according to the parameters of the transformer which the relay is controlling. An example transformer nameplate is shown in figure 68 with key parameters highlighted.

Table 20 shows how some of the key parameters shown on the transformer nameplate can be translated to SuperTAPP n+ relay settings.

Table 20 - Configuration of relay settings using transformer nameplate data

Nameplate Parameter	SuperTAPP n+ Setting	Comments
Peak current rating - I_{peak} (Amps)	Transformer rating (Amps)	
Nominal secondary voltage - V_{nom} (kV)	Nominal voltage (kV)	Sometimes the nominal secondary voltage of the transformer does not match the nominal network voltage
Peak MVA rating - S_{peak} (MVA)	Transformer rating (Amps)	This refers to the LV current. Calculation = S_{peak} / ($\sqrt{3} \times V_{nom}$)
LDC CT ratio (x:y)	Transformer rating (Amps)	Normally the primary rating (x) will represent the transformer LV peak current rating (Amps).
LDC CT ratio (x:y)	CT ratio (number)	The CT ratio is calculated as (x/y)
Non-peak impedance (%)	Transformer impedance (%)	The transformer impedance setting in the relay should correspond to the impedance for the transformer peak MVA rating. This is not always listed on the nameplate. Normally, and as a 'rule of thumb', this is 1% per MVA which would make a 24% setting for the transformer shown in Figure 68.
Tap position voltages (V)	Bandwidth (%)	The tap position voltages shown on the transformer nameplate allow a calculation of the tap step (%) which should in turn define the bandwidth setting (see section 4.5.1 and Figure 5)

Appendix C contains a settings sheet which can be used to record relay settings.


NON-PEAK MVA RATING
NOMINAL SECONDARY VOLTAGE
Transformer to BS 171 1970
M.V.A 12
Vector symbols Dy11
Frequency 50 hertz
k.V (no load)
H.V. 33 ± 8 x 1.25%
L.V. 11.5
Amperes
H.V. 210
L.V. 602.5
NON-PEAK CURRENT RATING
Inpedance volts on position 9
and at 75°C 12 %
NON-PEAK IMPEDANCE
Type of cooling ONAN
Insulation level (kVp) H.V. 170
L.V. 75
Oil quantities:- Transport 5336 litres 4.64 tonnes
Cooling plant 1242 litres 1.08 tonnes
Tapchanger tank 400 litres 0.35 tonnes
Mass:- Core and windings 12.35 tonnes
Complete transformer including oil but without cooling plant 20.49 tonnes
Cooling plant including oil transport excluding oil 4.88 tonnes
Manufacturers Serial No.
Year of manufacture
OFAF Continuous peak rating at 5° Ambient 24 M.V.A.
PEAK MVA RATING
Amperes H.V. 420
L.V. 1205
PEAK CURRENT RATING
HIGH VOLTAGE WINDING
Tap Changer
Plan of Cover
W.T.I. C.T. RATIO 1205 /3.8 A
L.D.C. C.T. RATIO 1205 /5.0 A
W.T.I. C.T. RATIO 1205 /3.8 A
LDC CT RATIO
LOW VOLTAGE WINDING
Tap - Changer shown on position 1 one phase only shown other phases identical.
TAP POSITION VOLTAGES
Sequence of operations raise and lower
Moving resistor contact makes
Main moving contact breaks
Main moving contact makes
Moving resistoe contact breaks.
Drawing No. PL 180014

HIGH VOLTAGE			LOW VOLTAGE
POSITION NO.	CONNECT IN PHASES A B C	VOLTAGE $A_{20}B_{20}C_{20}$	a_2 b_2 c_2
1	2 - 3	36300	
2	2 - 4	35888	
3	2 - 5	35475	
4	2 - 6	35063	
5	2 - 7	34650	
6	2 - 8	34238	
7	2 - 9	33825	
8	2 - 10	33413	11500
9	2 - 11	33000	
10	2 - 12	32588	
11	2 - 13	32175	
12	2 - 14	31763	
13	2 - 15	31350	
14	2 - 16	30938	
15	2 - 17	30525	
16	2 - 18	30113	
17	2 - 19	29700	

Figure 68 – Transformer nameplate

13.4 Relay Connections

In order that the relay can be commissioned for automatic voltage control the various connections to the system need to be tested. These tests should ideally be performed with the relay in non-auto control mode (any relay which has not been completely commissioned into use should not be switched to auto mode other than where specified in this commissioning guide) and for safety the raise and lower connector (block C – see section 10.2.4) should be disconnected to stop actual tap changer operations until required in later commissioning tests.

13.4.1 Analogue Inputs

VT Inputs

The VT inputs used for voltage measurements should be configured in the settings as appropriate for the application. VT inputs which are used for voltage control should have the 'function' set to 'Voltage Control' (usually V1 only, but both V1 and V2 for double-winding applications for voltage averaging – see section 9.2.2). For applications where a 'backup' voltage reference is required (see VT switching in section 9.2.1), V2 can be used with the 'Use' set to 'Voltage reference'.

Secondary Values

The voltage measurement inputs should first be tested to check that the secondary voltage measurement on each input is correct. This is easily done by comparing the voltage displayed on the instruments screen (shown in Figure 69) with that measured by a voltmeter.

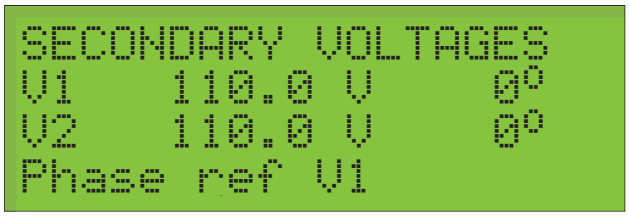


Figure 69 – Secondary voltages

Primary Values

The relay converts secondary values into primary values using VT ratio and VT phase settings. The VT ratio should be set according to the ratio of the system VT in use and can be checked by comparing the primary voltage measurement as indicated in the relay instruments with the known system primary voltage (as indicated elsewhere in the substation). The VT ratio in the relay is set as an absolute ratio and is calculated by dividing the primary rating of the VT with the secondary rating of the VT (e.g. for a VT with rating 11,000:110 V the ratio is 100).

Phase

The VT phase should be set according to the system VT connections as shown on the scheme drawings. It is more difficult to check, but is possible with reference to current measurements which are also in use (see section 4.3).

CT Inputs

The CT inputs used for current measurements should be configured in the settings as appropriate for the application. CT inputs used for transformer current measurement (normally the case) should have the 'function' set to 'Transformer' (usually one of the three available CT inputs only, but two for double-winding applications for load summation – see section 9.2.2). Other functions are available as described in section 9.2.

Secondary Magnitude

The current measurement inputs should first be tested to check that the secondary current measurement magnitude on each input is correct. This is easily done by comparing the current displayed on the instruments screen (shown in Figure 70) with that measured by a clamp CT on the secondary wiring of the main CT.

Figure 70 – Secondary currents

Primary Magnitude

The relay converts the secondary values into primary values using the CT ratio and CT turns settings. The CT ratio should be set according to the ratio of the system CT in use and is set as an absolute ratio, calculated by dividing the primary rating of the CT with the secondary rating of the CT (e.g. for a CT with rating 600:5 the ratio is 120).

The number of turns relates to the interposer turns, which is usually set in order to achieve 5 ‘Amp turns’ at full CT rating. Normally this results in 1 turn for a 5A CT secondary and 5 turns for a 1A CT secondary (other values are sometimes required to give more accuracy if the system is lightly loaded).

The CT ratio and number of turns settings can be checked by comparing the magnitude of the primary current measurements as indicated in the relay instruments with the known system values (as indicated elsewhere in the substation).

Phase

The CT phase should be set according to the system CT connections as shown on the scheme drawings. The CT sense setting is either ‘forward’ or ‘reverse’ and is used to correct a CT which may be connected with an incorrect polarity. Forward sense is usual for a transformer LDC CT, reverse for a feeder protection CT used to measure transformer current.

The relay instruments show the absolute measured angle between the VTs and CTs in use (see Figure 70), which is then used to calculate the resulting system power factor according the phase settings. It is useful to know what the real system power factor of the individual current measurements should be (by reference to other instruments in the substation) to check the primary values as shown in the relay instruments.

Figure 71 shows the possible VT and CT phase relationships and can be used to aid identification of correct phase settings.

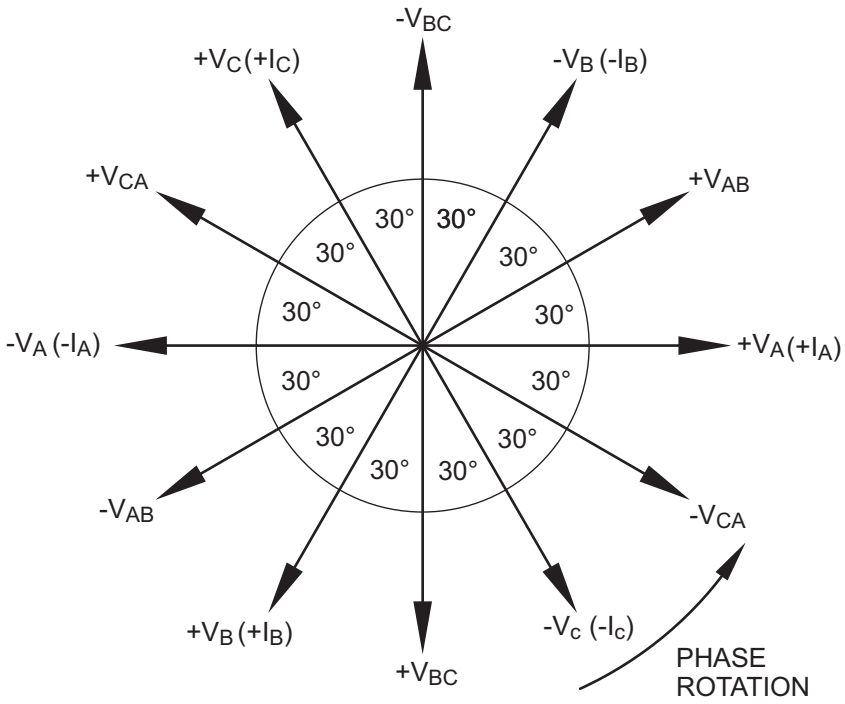
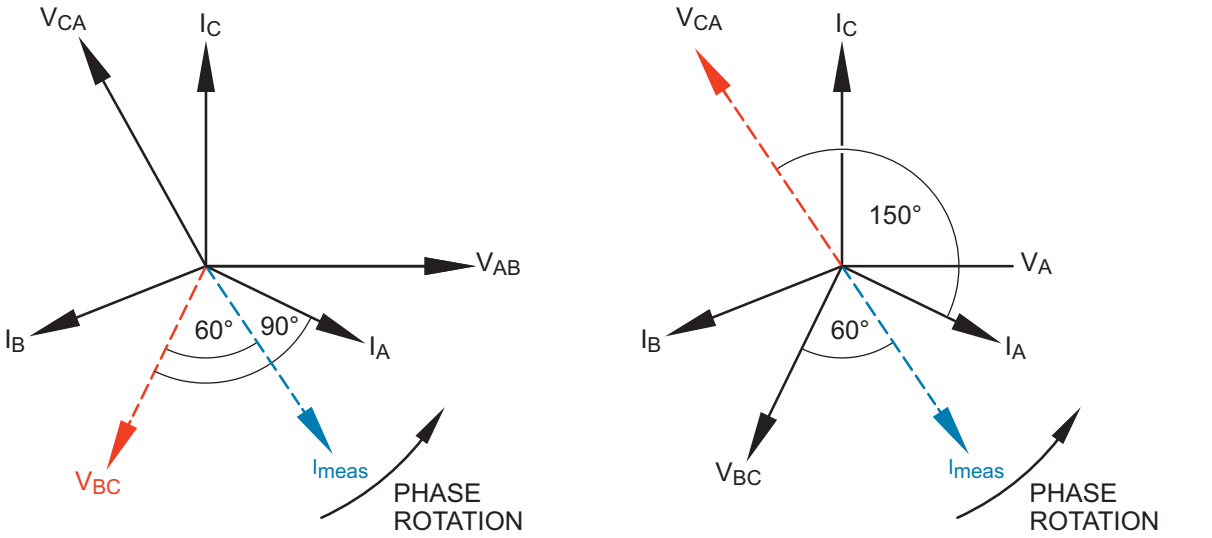


Figure 71 – VT / CT relationships

One of the most common problems is that the connections to the relay as shown on the scheme drawings are not correct and the relay settings therefore need to be amended to represent the actual phase connections. The effect of configuring the VT phase incorrectly in the relay setting is shown in Figure 72.



VT IN USE = B-C
CT = A
I_{meas} = +60°
RELAY VT SETTING = V_{BC}
⇨ RELAY CORRECTION = -90°
REAL SYSTEM PHASE = -30°
POWER FACTOR = +0.87 lagging

VT IN USE = B-C
CT = A
I_{meas} = +60°
RELAY VT SETTING = V_{CA}
⇨ RELAY CORRECTION = +150°
REAL SYSTEM PHASE = +210° = -150°
POWER FACTOR = -0.87 leading

Figure 72 – Effect of incorrect VT setting

13.4.2 Digital Inputs

The digital inputs should be tested to ensure that the response of the relay is correct. The status of inputs can be observed using the relay instruments to check that the relay is registering the appropriate signal (see Figure 73). More information relating to digital inputs can be found in section 10.2.7.

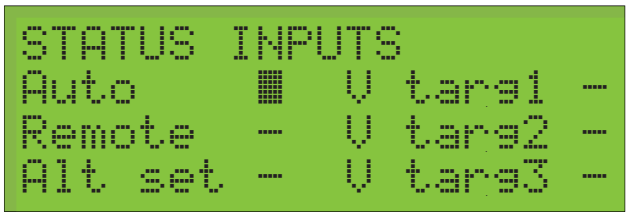


Figure 73 – Status inputs

The relay response depends on the type of input, each of which is considered in turn.

Voltage Adjustments

Inputs F1, F2 and F3 are available for voltage adjustments (offset and increment types) which are applied via telecontrol to amend the relay set point. The response of the relay following the application of each input (and combination of inputs) should be checked. This is most easily achieved by observing the change to the relay target voltage in the instruments screen shown below in Figure 74 or displayed on the default screen as shown below in Figure 75.

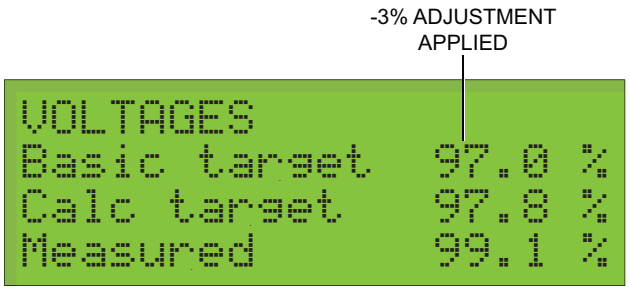


Figure 74 – Adjustment effect on target voltage

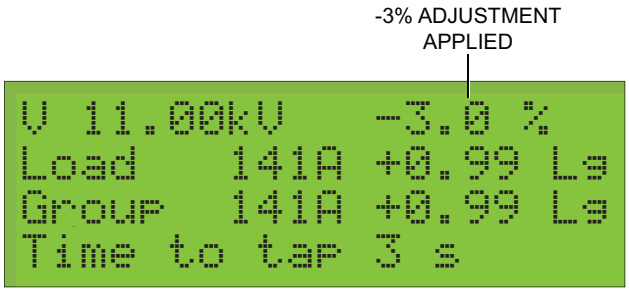


Figure 75 – Adjustment application

Mode of Control

Auto / Non-Auto

Inputs F4 and F5 can be used to switch the mode of control between non-auto and auto. This needs to be tested from each of the locations at which an operator could initiate such a change of control mode:

- At the relay control panel via push buttons/switches or the accompanying RTMU monitor relay non-auto/auto switch
- At the tap changer via local/remote switch
- At the control centre via remote control (SCADA communications)*

*only used where SCADA communications (DNP3, IEC61850 etc.) is in use

In each case, the operator should operate the appropriate switch/command and observe the change of state on the relay default screen as shown in Figure 76.

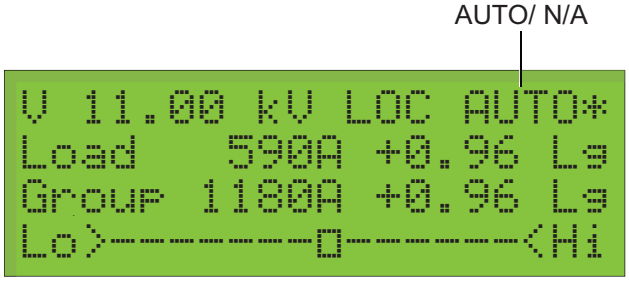


Figure 76 – Mode of control

Local / Remote

Inputs F4 and F5 can be used to switch the level of control between local and remote. It is required where SCADA communications (DNP3, IEC61850 etc.) is being used.

The relay response should be checked by operating a Local/Remote or equivalent switch (not available on the relay or accompanying RTMU but probably on the panel if SCADA has been implemented) and observing the change of state on the relay default screen as shown in Figure 77.

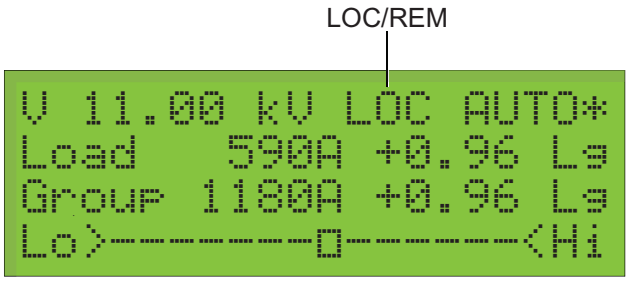


Figure 77 – Local / remote

Alternative Settings

Input F6 is available for the application of the alternative settings. Various settings can be configured to change on activation of this input which can result in changes to the relay response. Although there are too many permutations available to consider here, the activation of the input is displayed on the relay default screen as shown in Figure 78.

Figure 78 – Alternative settings

13.4.3 Outputs

Relay outputs should be tested to confirm correct scheme functionality. The status of outputs can be observed using the relay instruments as shown below in Figure 79. The effect of outputs should be checked and instruments used for fault finding. More information relating to outputs can be found in section 10.2.5.

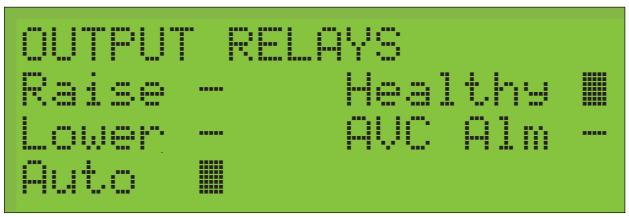


Figure 79 – Output statuses

Individual outputs are operated by manipulation of the relay settings as per the instructions shown below.

Raise and Lower

Outputs C1 (Lower) and C4 (Raise) can be tested by adjustment of the basic target setting of the relay to an appropriate level to promote a corresponding raise/lower operation (i.e. making the measured voltage out-of-band). The relay will need to be in auto control for this test (see section 13.6.2 for details of commissioning auto control mode). For example, if the measured voltage is 100% (of nominal voltage) and the bandwidth setting is ±2%, a raise operation can be achieved by adjusting the basic target setting to a value below 98% and a lower operation to a value above 102%*.

*although the common convention is for a raise operation to produce an increase in LV voltage (i.e. a decrease in transformer ratio), some tap changers operate in the opposite sense. This should be checked for each application. The convention used for the SuperTAPP n+ relay is that a low voltage condition will result in a raise operation and a high voltage condition will result in a lower operation. The relay raise and lower outputs should be connected appropriately.

Relay Healthy

Output D2 (Relay Healthy) should be activated when the relay is powered up and operating normally.

Relay Fail

Output D4 (Relay Fail) should be activated when the relay is powered down.

AVC Alarm

Output D5 (AVC Alarm) is activated by various operational conditions indicating that there is a voltage control problem. The easiest way to test the output is to force a ‘zero voltage’ state by disconnection of the VT input(s) (connector group E). The alarm will not be activated until the alarm time has passed (default setting is five minutes).

Non-Auto / Auto Control

Outputs D6 (Non-auto control) and D7 (Auto control) are activated when the relay is in the equivalent mode of control. If the relay is used in conjunction with an RTMU module, the easiest way of changing the control mode is by operating the auto/non-auto switch (correct operation depends on correct wiring between the SuperTAPP n+ and the RTMU).

13.4.4 CAN Bus

Communications can be tested by reference to related instruments screens which show the units connected and also status information where there are problems (see Figure 80). Each relay should be configured to have a unique transformer ID, normally to match the transformer to which it is connected. Relays connected to paralleled transformers should be configured to operate in the same group. More information relating to CAN bus communications can be found in section 10.2.8.

Figure 80 – CAN bus status

If the individual relays are connected to transformers which are on load and are configured to operate in the same group, the group load on the relays should match each other.

13.5 Levels of Control

There are two levels of control for voltage control as follows:

- Local – tap changer is controlled at the substation (at the tap changer or at the tap changer control panel/relay)
- Remote – tap changer is controlled via the relay by SCADA communications (DNP3, IEC 61850 etc.)

Remote control is only possible with an accompanying ENVOY unit. If there is no ENVOY then the relay is permanently in local control.

13.5.1 Local Control

An easy way to test relay operation in local control is to switch between Auto and Non-Auto (using the RTMU relay switches or equivalent panel switches) and confirm the appropriate change of relay control mode (see figure 76).

No SCADA commands should have any effect when the relay is in local control mode.

13.5.2 Remote Control

The first test in remote control mode should be to confirm that no local operations are possible. An easy way to test this is to switch between Auto and Non-Auto (using the local RTMU relay switches or equivalent panel switches) and confirm that no change of state has taken place (the relay should ignore the change of state).

The number of functions available depends on the application, but tests to confirm remote control can include the following:

- Switching the relay between Auto and Non-Auto from SCADA and observing the appropriate change of state (see figure 76).
- Switch the relay to Non-Auto from SCADA and issue remote raise and lower operations (appropriate voltage changes should be observed with corresponding fascia indications)
- Switch the relay to Auto from SCADA and issue target voltage adjustments which can be viewed on the relay instruments screens (see figure 74).

13.6 Modes of Operation

There are two modes of operation for the relay as follows:

- Non-Auto Mode – operator controls the tap changer
- Auto Mode – relay controls the tap changer

13.6.1 Non-Auto

The main test for this mode of control is to confirm that tap changer operations can be performed from the following locations:

- At the relay control panel via raise/lower push buttons/switches or the accompanying RTMU monitor relay
- At the tap changer via raise/lower switch

- At the control centre via remote control (SCADA communications)*

*only used where SCADA communications (DNP3, IEC61850 etc.) is in use

In each case the relay will operate as normal, indicating all measurement data as per the resulting conditions, but will not issue any corrective tap changer operations or AVC alarms associated with the operational state (e.g. an overvoltage condition). This should be tested by operating the tap changer to produce an out-of-band voltage condition (or by injection testing) and confirming that no corrective tap changer operations take place (wait for longer than the initial tap timer setting) or AVC alarms are issued (wait for longer than the alarm time setting).

When the relay is switched to auto control from non-auto and the voltage has been out-of-band for more than the initial tap timer, it will initiate an immediate corrective tap changer operation (this can be tested once auto control has been tested – see next section).

13.6.2 Auto

These tests should confirm that the relay can automatically correct system voltages according to the application requirements. Basic relay operation should be tested first before application-dependent functions such as LDC or circulating current are considered.

Basic Operation

These tests should be performed with the relay measuring voltage only (to ensure no biasing for circulating current control or LDC etc.) and with the CAN bus disconnected or paralleled units configured into different groups (to ensure that no other units are influencing the relay response). These tests can therefore be performed with the transformer off-load or with the CT(s) shorted.

The relay should remain in non-auto control mode until specified.

Upper and Lower Voltage Band

The test is to make sure that the voltage levels at which the relay initiates tap changer operations are correct. The upper band level should be equal to the basic target setting plus the bandwidth setting and can be confirmed by noting the level at which the voltage high LED is illuminated. The lower band level should be equal to the basic target setting minus the bandwidth setting and can be confirmed by noting the level at which the voltage low LED is illuminated.

Ideally this is confirmed by injection testing (applying the appropriate voltage to the VT inputs from a test set). If injection testing is not possible then the system voltage must be used. In order to check the relay response, the basic target voltage setting (V_{basic}) can be modified to 'force' an out-of-band condition dependent on the measured system voltage (V_{meas}):

- High voltage: $V_{basic} = V_{meas}$ – bandwidth
- Low voltage: $V_{basic} = V_{meas}$ + bandwidth

Tap Timers

These tests confirm the relay initial tap and inter-tap timers. The relay should be in auto control for this test but the raise and lower outputs (connector block C – see section 10.2.4) can be disconnected for safety so that no actual tap changer operations are initiated.

The initial timer is confirmed by measuring the time between an out-of-band voltage (produced as per previous section) and initiation of the appropriate tap operation (lower for high voltage and raise for low voltage).

The inter-tap timer is confirmed by measuring the time between initiation of the first tap operation and a subsequent tap operation. This is only possible if the out-of-band condition persists after the first tap operation, i.e. if the voltage has not been corrected. This will be the case since the relay raise and

lower outputs should not be connected to the tap changer at this stage (relay connector block C is disconnected for safety as described previously).

The key for the inter-tap timer is that it is longer than the operational time of the tap changer itself (for safety at least 10 seconds longer).

Fast Tap

This is only applicable where the fast-tap facility is being used (fixed 4 second timer for certain voltage conditions – see section 4.5.1). In order to test fast-tap is operating as desired, the appropriate condition (e.g. voltage more than 2% above upper band) should be created and the 4 second timer between when the out-of-band voltage is applied (indicated by fascia LEDs) and when a corrective tap operation is initiated should be observed.

Voltage Correction

Basic operation is confirmed with observation of real tap changer operations which correct system voltages (high and low). This test can only take place with the transformer energised. The relay should be in auto control mode and the raise and lower connector block (C) should be connected. There are three ways to test this:

1. Wait for the system voltage to drift out-of-band (could take some time – no advised).
2. Modify the basic target setting to promote the out-of-band condition.
3. Manually operate the tap changer to create the out-of-band condition and then switch the relay back to auto control mode.

The result of the tap changer operation should be a corrected system voltage to within the band – i.e. a ‘voltage normal’ condition. The voltage change observed will be dependent on the tap step of the tap changer (calculated from the nameplate – see section 13.3 and figure 68) and the number of paralleled transformers. For example, if the tap step of the tap changer is 1.25% and there are two transformers operating in parallel, the observed voltage deviation when one of the tap changers operates will be 0.625%.

Circulating Current

Circulating current is only relevant for transformers which are being operated in parallel. As described in section 8.4, transformers can be paralleled at a site or across the network, although the former is much more common. The relay calculates both components of circulating current (site and network) and converts it into a corrective bias, V_{circ}. This bias promotes tap changer operations to reduce the circulating current.

The transformer LDC CT and CAN bus must be connected for this test since circulating current control depends on the summed transformer load.

The test can be performed in two parts as follows:

1. Confirmation of circulating current calculations
2. Corrective tap changer operations.

Calculations

Circulating current calculations can be confirmed by reference to instruments screens which show the calculated values of site circulating current and network circulating current (see figure 61 and table 18 for how to navigate to the ‘circulating currents’ instrument screen).

In order to promote the flow of circulating current and confirm the calculations, the site transformers need to be tapped apart. This is done manually with the relay in non-auto control mode. The relay can be left in non-auto to check the calculations.

The transformer which is on the lower ratio (normally the higher tap position) and therefore trying to output the higher voltage will export circulating current (lagging Vars) as shown earlier in figure 27. This will be displayed in the instruments as negative site circulating current. The resulting voltage bias for circulating current will also be negative and reduce the relay target voltage (this can be checked in other instruments screens) to an extent where it displays an out-of-band condition (high voltage) and wants to tap down.

The transformer which is on the higher ratio (normally the lower tap position) and therefore trying to output the lower voltage will import circulating current (leading Vars). This will be displayed in the instruments as positive site circulating current. The resulting voltage bias for circulating current will also be positive and increase the relay target voltage (this can be checked in other instruments screens) to an extent where it displays an out-of-band condition (low voltage) and wants to tap up.

If the direction of the site circulating current and corresponding bias is not correct then the CT connection should be checked to confirm polarity (see section 13.4.1).

Network circulating current is more difficult to confirm since it is not possible to know the relative output voltages of transformers paralleled across the network. Despite this, the calculation can be checked by reference to the measured group load of the relay. If the group load is more lagging than the relay target power factor setting, the resultant network circulating current should be negative. If the group load is more leading than the relay target power factor setting, the resultant network circulating current should be positive.

Corrective Operations

In order to complete the tests for circulating current the above situation should be created and then the relay(s) switched to auto control. The result should be initiation of tap changer operations which bring the tap positions to a level where the system voltage is correct and the circulating current is minimised.

The test should be repeated in the opposite direction, i.e. the transformer which was tapped up relative to the other one should also be tapped down to make sure the calculations work in both directions.

LDC

Load drop compensation has been described in section 8.5. Since relay operation has already been confirmed in previous tests, the only test required for LDC is that the voltage bias is correct for the existing load conditions. The bias depends on the LDC setting, the group load, the target power factor setting and the site firm capacity as follows:

V_{LDC} = k × LDC setting × (group load / firm capacity)

where k is a coefficient (between 0 and 1) representing the component of group load at target power factor setting (see figure 29) and V_{LDC} is capped at the LDC setting.

The biases can be checked by reference to the instruments screens mentioned in the previous section. The relay can therefore be in non-auto mode of control for this test.

The normal situation is where the transformer is supplying real and reactive power to the network. The measured transformer current in this situation shows a positive lagging power factor (positive group load). The effect of LDC should be a positive voltage bias such that the relay target voltage increases and the relay wants to tap up (with a corresponding low voltage indication). If the direction of the bias is not correct then the CT connection should be checked to confirm polarity (see section 13.4.1).

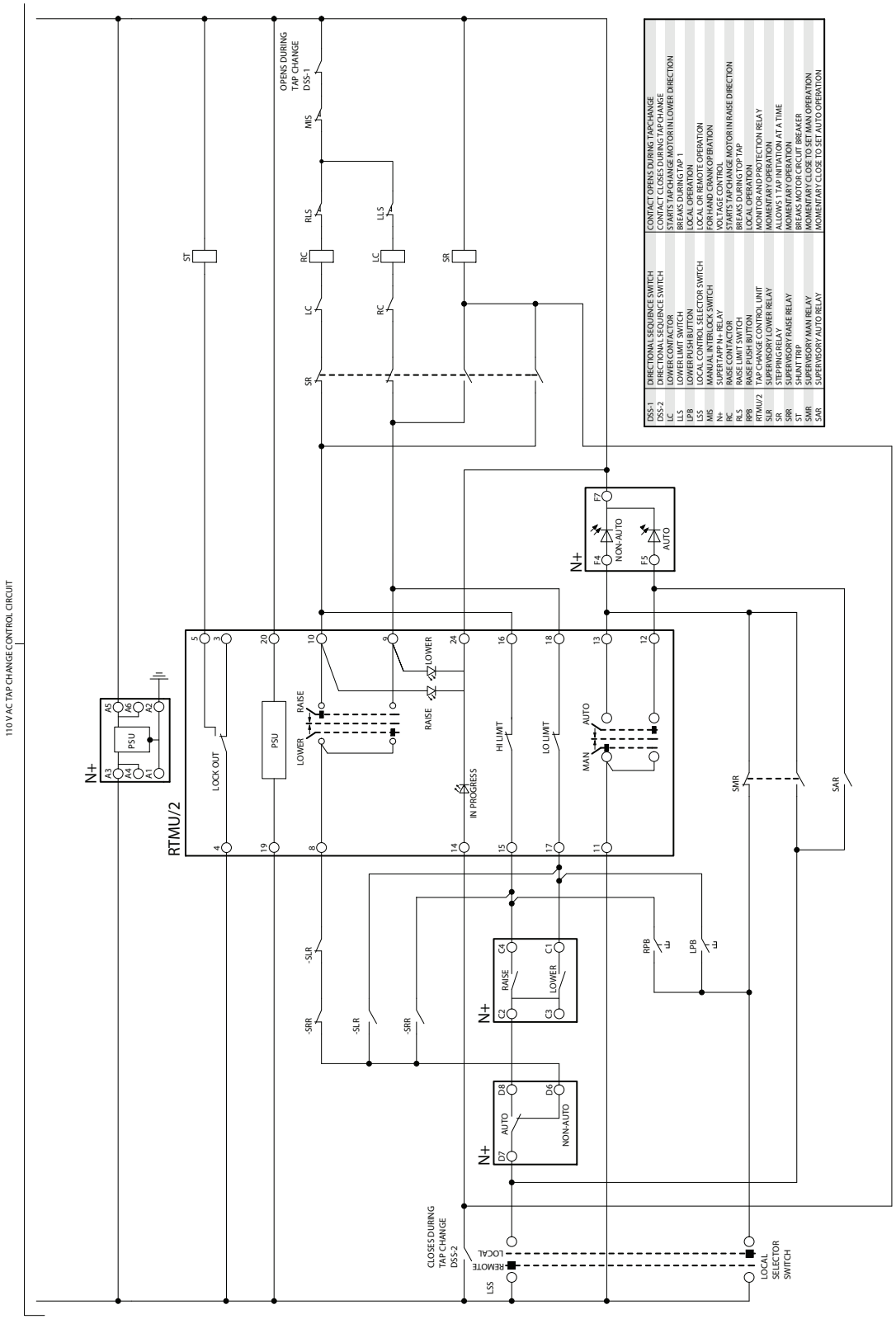
Where the transformers are in reverse power and the group load is negative, e.g. where there is a high level of embedded generation on the network, the voltage bias is dependent on the relay reverse LDC setting as follows:

- Reverse LDC on: V_{LDC} as per above equation but capped at the reverse LDC setting
- Reverse LDC off: V_{LDC} = zero

Although it is difficult to test this with real reverse power on the transformer(s), the effect can be simulated and LDC response observed by reversing the sense of the CT inputs in use (this should reverse the group load). Once this test has been performed the CT ‘sense’ setting should be changed back to the correct polarity.

If reverse LDC is on, the effect will be to reduce the target voltage and make the relay want to tap down (with a corresponding high voltage indication). If reverse LDC is off there should be no bias applied. The LDC bias can be checked using the instruments screens.

Appendix A - SuperTAPP n+ Scheme Drawings


110 V AC TAP CHANGE CONTROL CIRCUIT
RTMU/2
N+
PSU
LOCK OUT
RAISE
LOWER
IN PROGRESS
HI LIMIT
LO LIMIT
AUTO
MAN
NON-AUTO
OPENS DURING TAP CHANGE DSS-1
CLOSES DURING TAP CHANGE DSS-2
LOCAL
REMOTE
LSS
LOCAL SELECTOR SWITCH
SMR
SAR
RPB
LPB
-SLR
-SRR
DSS-1 DIRECTIONAL SEQUENCE SWITCH — CONTACT OPENS DURING TAP CHANGE
DSS-2 DIRECTIONAL SEQUENCE SWITCH — CONTACT CLOSES DURING TAP CHANGE
LC LOWER CONTACTOR — STARTS TAP CHANGE MOTOR IN LOWER DIRECTION
LLS LOWER LIMIT SWITCH — BREAKS DURING TAP 1
LPB LOWER PUSH BUTTON — LOCAL OPERATION
LSS LOCAL CONTROL SELECTOR SWITCH — LOCAL OR REMOTE OPERATION
MIS MANUAL INTERLOCK SWITCH — PREVENTS AUTOMATIC OPERATION
N+ SUPERTAPP N+ RELAY — VOLTAGE CONTROL
RC RAISE CONTACTOR — STARTS TAP CHANGE MOTOR IN RAISE DIRECTION
RLS RAISE LIMIT SWITCH — BREAKS DURING TOP TAP
RPB RAISE PUSH BUTTON — LOCAL OPERATION
RTMU/2 TAP CHANGE CONTROL UNIT — MONITOR AND PROTECTION RELAY
SLR SUPERVISORY LOWER RELAY — MOMENTARY OPERATION
SRR SUPERVISORY RAISE RELAY — MOMENTARY OPERATION
ST SHUNT TRIP — BREAKS MOTOR CIRCUIT BREAKER
SMR SUPERVISORY MAN RELAY — MOMENTARY CLOSE TO SET MAN OPERATION
SAR SUPERVISORY AUTO RELAY — MOMENTARY CLOSE TO SET AUTO OPERATION

Appendix B - Commissioning Sheet

Relay serial number ……

Transformer ID …… Site Name ……

Date ……

TYPE	TEST	DONE	NOTES
General	Sound insallation		
	Software version		
Relay Settings	All settings checked		
	All settings recorded (see Appendix C)		
VT Inputs	V1 secondary values		
	V1 primary values		
	V1 phase		
	V2 secondary values*		
	V2 primary values*		
	V2 phase*		
CT Inputs	C1 secondary values		
	C1 primary values		
	C1 phase		
	C2 secondary values*		
	C2 primary values*		
	C2 phase*		
	C3 secondary values*		

TYPE	TEST	DONE	NOTES
	C3 primary values*		
	C3 phase*		
Digital Inputs	Voltage adjustment 1		
	Voltage adjustment 2		
	Voltage adjustment 3		
	Auto / Non-Auto		
	Local / Remote		
	Alternative settings		
Outputs	Raise		
	Lower		
	Relay Healthy		
	Relay Fail		
	AVC Alarm		
	Non-Auto		
	Auto		
CAN Bus	Group configuration		
Local Control	Switch between Auto and Non-Auto		
	SCADA ineffective		
Remote Control	Local control ineffective		
	SCADA effective		
Non-Auto Control	Control at remote panel		

TYPE	TEST	DONE	NOTES
	Control at OLTC		
	SCADA control (only for remote control)		
Auto Control – Basic Operation (voltage-only)	Upper band level		
	Lower band level		
	Initial timer		
	Inter-tap timer		
	Fast tap		
	Corrective operation		
Auto Control – On Load Operation (voltage and current)	Circulating current – calculations		
	Circulating current – corrective operations		
	LDC – forward power		
	LDC – reverse power		

* Not shown for a basic model

Appendix C - Settings Sheet

Relay serial number ……

Transformer ID …… Site Name ……

Date ……

Setting Type		Setting	Value	Default setting
BASIC		Target voltage		100 %
		Bandwidth		1.5 %
		LDC		2.5%
		Reverse LDC		Disabled
		Initial tap time		120 sec
		Inter-tap time		15 sec
		Tap pulse length		2 sec
		Fast tap		Down
NETWORK		Nominal voltage		11 kV
		Firm capacity		1575 A
		Power factor		0.96 lag
		Network circ. factor		10%
		Phase rotation		'ABC'
TRANSFORMER		Transformer ID		1
		Group ID		1
		Transformer rating		1575 A
		Transformer impedance		30 %
		Overcurrent level		130 %
VT's & CT's	V1	V1 function*		Voltage Control
		V1 ratio		100
		V1 phase		B-C
	V2 *	V2 function *		Unused
		V2 ratio *		100
		V2 phase *		B-C
	C1	C1 function*		Transformer
		C1 interposer turns		5
		C1 ratio		1600
		C1 phase		A
		C1 sense		Normal
	CT2 *	C2 function *		Unused
		C2 interposer turns *		5
		C2 ratio *		1600
		C2 phase *		A

Setting Type		Setting	Value	Default setting
		C2 sense *		Normal
	CT3 *	C3 function *		Unused
		C3 interpose turns *		5
		C3 ratio *		1600
		C3 phase *		A
		C3 sense *		Normal
VOLTAGE TARGET ADJUSTMENT		Type		Fixed
		Target 1		-3 %
		Target 2		-6 %
		Target 3		3 %
		Step size		1 %
GENERATION *		Load ratio *		0 %
		Generator rating *		0 A
		Generator Bias *		0 %
		Reverse LDC level*		Disabled
		Max reverse load*		Disabled
		Reverse power factor*		Disabled
ALARMS		Alarm time		300 sec
		Low voltage inhibit		80%
ALTERNATIVE SETTINGS		Target voltage		100 %
		Bandwidth		1.5 %
		LDC		2.5%
		Reverse LDC		Disabled
		Group ID		1
		Load ratio *		0 %
		Generator bias *		0 %
		Firm capacity		1575 A
		Power factor		0.96 lag
		Reverse power factor*		Disabled
		Reverse LDC level*		Disabled
		Max reverse load*		Disabled
		Network circ. factor		10%
		Feeder measurements *		Ignore
RELAY CONFIG		Auto select mode		Edge
		Restart relay	No	No
		Clear comms records	No	No
		Restore defaults	No	No
		Advanced relay code		0

* Not shown for a basic model

Appendix D - Type Test Results

Atmospheric Environment Requirements

ENA Technical Specification 48-5 Clause	Preferred Standard/Procedure	Specified Test Level	Compliance Y or N	Actual Test Level	Remarks
4.1 - Temperature Cold Heat	IEC 60068-2-1	-10℃, 96 hours, operate OR -25℃ , 16 hours, operate	Y	-10℃, 96 hours, operate	
		-25℃, 96 hours, operate (for outdoor equipment)			
		-25℃, 96 hours, storage OR -40℃, 16 hours, storage	Y	-25℃, 96 hours, storage	
4.1 - Temperature Dry Heat	IEC 60068-2-2	+55℃, 96 hours, operate OR +70℃, 16 hours, operate	Y	+55℃, 96 hours, operate	
		+70℃, 96 hours, operate (for outdoor equipment)			
		+70℃, 96 hours, storage	Y	+70℃, 96 hours, storage	
4.2 - Relative Humidity	IEC 60068-2-3	93%, 40℃, 56 days OR			

ENA Technical Specification 48-5 Clause	Preferred Standard/Procedure	Specified Test Level	Compliance Y or N	Actual Test Level	Remarks
4.2 - Relative Humidity (alternative)	IEC 60068-2-30,	93%, 40℃, 6 off 24 hour cycles of +25 to +55℃	Y	6 off 24 hour cycles of +25 to +55℃	
4.3 – Enclosure	IEC 60529	IP50	N		
		IP54 (for outdoor equipment)	N		

Mechanical Environment Requirements

ENA Technical Specification 48-5 Clause	Preferred Standard/Procedure	Specified Test Level	Compliance Y or N	Actual Test Level	Remarks
5.1 – Vibration	IEC 60255-21-1	Response Class 1	Y		
		Response Class 2 (Where integral with Switchgear	N/A		
		Endurance Class 1	Y		
5.2 – Shock	IEC 60255-21-2	Response Class 1	Y		
		Response Class 2 (Where integral with Switchgear	N/A		
		Withstand Class 1	Y		
5.2 – Bump	IEC 60255-21-2	Class 1	Y		
5.3 – Seismic	IEC 60255-21-3	Class 1	Y		

Electrical Environmental Requirements

ENA Technical Specification 48-5 Clause	Preferred Standard/Procedure	Specified Test Level	Compliance Y or N	Actual Test Level	Remarks
6.1 - DC Supply Voltage - 48 V DC	IEC 60255-6	Table 1, remain within claimed accuracy from 38.5 to 53 V with >60 V continuous withstand	N/A		AC power supply
6.1 - DC Supply Voltage - 110 V DC	IEC 60255-6	Table 1, remain within claimed accuracy from 87.5 to 137.5 V with >143 V continuous withstand	N/A		AC power supply
6.1 - DC Supply Voltage dips, short interruptions and Voltage variations immunity test	IEC 60255-11	2, 5 & 10 ms interruption, no affect	N/A		AC power supply
		>10 ms interruption, no maloperation with any reset.	N/A		AC power supply
		12% AC ripple	N/A		AC power supply
6.1 - DC Supply Voltage – General		Ramp up and down over 1 minute, or similar	N/A		AC power supply
6.1 – DC Supply Voltage - Low Burden Trip Relays		Capacitive Discharge ESI 1	N/A		AC power supply
6.1 – DC Supply Voltage - High Burden Trip Relays		Capacitive Discharge ESI 2	N/A		AC power supply
6.2 – AC Supply Voltage	IEC 60255-6	Min and max declared	Y		80 – 260 V AC

ENA Technical Specification 48-5 Clause	Preferred Standard/Procedure	Specified Test Level	Compliance Y or N	Actual Test Level	Remarks
6.3 – Thermal requirement - CT inputs		2.4 x In, continuous 3.0 A, 20 mins 3.5 A, 10 mins 4.0 A, 5 mins 5.0 A, 3 mins 6.0 A, 2 mins	N/A		1000:1 CT interposer used (extremely low burden) – therefore isolated from primary CT **what is the withstand capability of the interposer CT ? It is not N/A !
6.4 – Thermal requirements - VT inputs		120% of Vn, continuous	Y		Max voltage = 150 V continuous (136% of Vn)
6.5.1 – Insulation – Dielectric	IEC 60255-5	Test values selected according to insulation voltage. High Impedance circulating current schemes, test at 2.5 kV. Circuits connected to instrument transformers or batteries, rated insulation not below 250 V, test at 2.0 kV. Open output relay contacts 1 kV.	Y		DC level up to 2.8 kV PASS AC level up to 1 kV PASS
6.5.2 – Insulation – Impulse Voltage	IEC 60255-5	Test at 5 kV, 0.5 J	N/A		NOT TESTED – test house did not have required equipment

Electromagnetic Compatibility (EMC) Requirements

In general the radiated field and ESD tests apply to the enclosure and the remaining tests apply to all input/output ports including the auxiliary energising supply port, CT/VT connections, status/alarm connections and communication ports, unless stated otherwise.

ENA Technical Specification 48-5 Clause	Preferred Standard/Procedure	Specified Test Level	Compliance Y or N	Actual Test Level	Remarks
7.1 – Oscillatory waves immunity test (High Frequency Disturbance)	IEC 60255-22-1	Class III, 1 MHz, 2.5 kV common, 1 kV diff. Applied to all ports, except diff on comms port at the discretion of the panel.	N/A		NOT TESTED – test house did not have required equipment
7.2 – Electrostatic Discharge (ESD) immunity tests	IEC 60255-22-2	Class III, 6 kV, contact, 8 kV air. Applied to enclosure.	N – See Remarks		Passed but hardware error reported – normal function resumed
7.3 – Radiated electromagnetic field disturbance test (RFI)	IEC 60255-22-3	10 V/m, 1 kHz, 80 to 1000 MHz sweep and 80, 160, 450, 900 MHz spot frequencies.	N - See Remarks		Passed with higher level of tolerance (up to ±6%)
7.4 – Radiated electromagnetic field from digital radio telephones immunity test	IEC 60255-22-3	10 V/m, 900 and 1890 MHz.	N - See Remarks		Passed with tolerance level of ±6%
7.5 – Electrical fast transient/burst immunity	IEC 60255-22-4	Level IV, 4 kV. Applied to all ports.	N - See Remarks		Passed but data parameters displayed on the screen shifted- Normal function resumed

ENA Technical Specification 48-5 Clause	Preferred Standard/Procedure	Specified Test Level	Compliance Y or N	Actual Test Level	Remarks
7.6 – Surge immunity test	IEC 60255-22-5	Level III, 2 kV common, 1 kV differential. (Level 4, 4 kV, 2 kV preferred for CT and VT inputs.) Applied to all ports.	N - See Remarks		Passed but raise command was issued - self recoverable
7.7 – Conducted electromagnetic field disturbance tests	IEC 60255-22-6	10 Vrms, 80% mod, 1 kHz. 0.15 to 80 MHz sweep and 27 and 68 MHz spot frequencies. Applied to all ports.	Y		
7.8.1 – Power Frequency Interface magnetic field immunity test	IEC 61000-4-8	1000 A/m for 1 sec and 100 A/m for 1 min. Applied to enclosure. Not currently mandatory.	Y		
7.8.2 – Power Frequency Interface – General	IEC 60255-22-7	Level 4, 300v for 1 s at 50 hz, common mode.	N/A		NOT TESTED – test house did not have required equipment
7.9 – Pulse magnetic field immunity test	IEC 61000-4-9	6.4/16 μs magnetic pulse, 1000 A/m. Applied to enclosure. Not currently mandatory.	Y		
7.10 – Damped oscillatory magnetic field immunity test	IEC 61000-4-10	0.1 and 1.0 MHz, 100 A/m. Applied to enclosure. Not currently mandatory.	Y		
7.11 – Communication channel Noise immunity	IEC 60834-1 & IEC 60834-2	See standard	Y		

ENA Technical Specification 48-5 Clause	Preferred Standard/Procedure	Specified Test Level	Compliance Y or N	Actual Test Level	Remarks
7.12 – Conducted and Radiated Emission	IEC 60255-25	Class A, Conducted, power supply: 0.15 to 0.5 MHz, 79dB(µV) quasi pSP Power Systemsk, 66 dB(µV) average, 0.5 to 30 MHz, 71dB(µV) quasi pSP Power Systemsk, 60 dB(µV) average. Radiated, Enclosure at 10m: 30 to 230 MHz, 40 dB(µV) quasi pk, 230 to 1000 MHz, 47dB(µV) quasi pk.	Y		

Notes